AN ELEMENTARY MANUAL

OF THE

STEAM ENGINE

CONTAINING ALSO

A CHAPTER ON THE THEORY, CONSTRUCTION AND OPERATION OF INTERNAL COMBUSTION ENGINES

FOR THE OPERATING ENGINEER

BY

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PREFACE.

The author has for some years been engaged as an instructor in engineering. He has enjoyed intimate acquaintance with students and with young men engaged in the actual operation of steam plants. Many students of steam engineering, while they may have had excellent training in mathematics and general science, are yet so immature that they do not readily make practical application of their general knowledge; and the average operating man, despite his experience, realizes his lack of adequate grasp of fundamental principles — a lack which hampers his advancement.

To help both classes of men, teaching them to think and to reason, they must be taught the subject in a manner which may supplement their present partial knowledge.

Great difficulty has been experienced in securing a textbook fulfilling such requirements. The following pages have therefore been written with a view to presenting the fundamental principles of the use of steam and steam engines in an elementary manner. It is hoped that in thus offering in simple form the results of an experience gained in active engineering practice, a satisfactory foundation and guide may be furnished for further study.

E. V. L.

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Elementary Steam Engineering.

CHAPTER I.

RECIPROCATING STEAM ENGINES.

STEAM ENGINES are divided into various classes according to their uses, as stationary, locomotive, marine, and portable.

The essential principles are alike in all cases. They differ only in details due to varying conditions and the uses to which they are to be put.

An engine may be horizontal, vertical, or a combination of both. It may have one or more cylinders. It may be operated condensing or non-condensing, depending on whether the steam, after doing its work in the cylinder, is allowed to pass to a condensing apparatus or direct to the atmosphere.

In all cases where mechanical power is developed by means of such an engine, the essential construction is that of a piston moving in a cylinder due to a pressure of steam delivered first on one side and then the other. This will produce a reciprocating, or forward and backward, motion of the piston, which motion is transformed into rotary motion by proper mechanical means.

The admission of the steam to either side of the piston is controlled by valves. The varying types and con-

struction of the valves are largely indicative of the different types of engines.

Perhaps the simplest and, up to quite recent times, the most extensively used engines are those of the slide-valve type, and as the description of this type of engine will largely serve for all kinds it will be described first.

THE SLIDE-VALVE ENGINE.

Referring to Fig. 1 we have the cylinder A, within which is the piston B which is moved from one end to the other by steam entering alternately through the openings CC′, the action being regulated by the slide valve D. The piston rod E passes through the front head of the cylinder.

The piston is composed of several parts, the piston proper *a*, Fig. 2, and the follower *b*, which is fastened to the piston by several bolts, leaving an annular ring space extending completely around the piston.

If the piston were made to fit tightly into the cylinder there would be no opportunity for the steam to escape, but the warping of the cylinder walls, expanding unevenly, due to variations in temperature, would cause the piston to bind.

To prevent this, the piston is made slightly smaller in diameter than the cylinder, and, in order to prevent leakage, the annular space B, Fig. 2, is filled by piston rings, the use of which is to prevent the leakage of steam and yet allow a rapid and free piston movement.

One of the simpler forms of piston rings is shown in Fig. 3. This consists of a cast-iron ring slightly larger in diameter than the internal bore of the engine cylin-

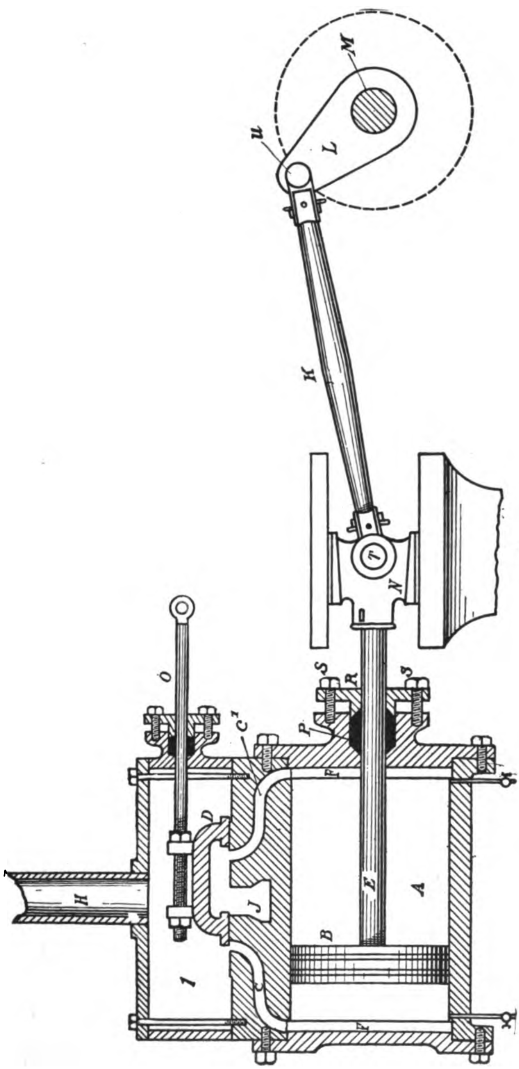


Fig. 1.

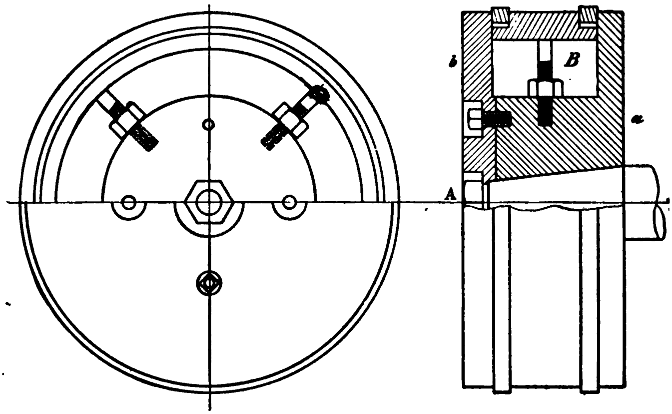


Fig. 2.

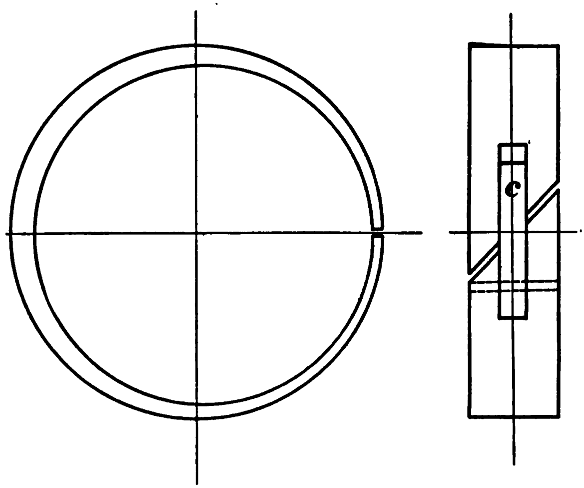


Fig. 3

der, turned eccentrically so that one side of the ring will be thinner than the other. The ring is cut diagonally across the thin portion as shown. The cutting reduces the length sufficiently that it may be sprung into place.

In order to prevent leakage through the cut, the tongue C is placed in the slots provided. The result of all this is that the piston is free to move, because the packing ring may give and take without binding on account of any irregularity of the diameter, and it continues to spring outward as wear takes place, thus keeping everything steam-tight. On larger engines the piston rings are sometimes made in sections and pressed outward by springs inserted between the piston and the piston ring.

On large pistons where several rings are to be employed, instead of simply cutting grooves in the piston and springing the rings into place, a large ring is employed called the bull ring. This contains grooves on the edges forming recesses in which the piston rings proper are placed, while the bull ring is pressed outward by means of studs and nuts as shown in the partial section of Fig. 2.

The method of fastening the piston to the piston-rod is indicated in Fig. 2.

The piston-rod is here shown tapered on the end. This rod fits a similar tapered opening in the piston. Both are then drawn tightly together by the nut A. This is made possible on account of the tapered form. There is little possibility of shaking loose due to the vibration incidental to the engine's action, and it is

much more easily machined and fitted than would be the case if a plain cylindrical joint were used.

Steam is prevented from leaking through the opening in the cylinder head, where the piston-rod passes out, by means of suitable packing placed in the stuffing box P, Fig. 1. As will be seen here, the material of this cylinder head is so formed as to produce a circular recess around the rod, the lower end of this recess being cut to an angle of about forty-five degrees. The collar R, Fig. 1, called the gland, fits easily into this recess. The inner portion of the gland is tapered in a similar manner to the bottom of the recess. The gland may be drawn in by means of the studs and nuts S S shown on either side. When thus held in position the space P is filled with packing. The action of the gland is to force the packing snugly against the piston-rod, allowing freedom of movement but maintaining a steam-tight joint.

The cylinder of the engine is turned slightly larger at each end as shown at F, Fig. 1, the object of which is to allow the piston to over-run at the end of each stroke. If this were not provided for, the constant rubbing of the piston would, in time, wear a distinct shoulder against which it would strike and possibly cause damage. The cylinder heads are fastened to the cylinder by means of studs and nuts as shown. The stud is a short metal bolt threaded at either end and having a blank space in the center.

When the steam enters from the boiler through the main steam pipe H, it occupies a space I, called the steam chest; from the steam chest it enters the cylin-

der through the ports CC′. The position of the slide valve D determines in which direction the steam shall enter. When the slide valve is in the position shown in Fig. 1, steam from the steam chest will enter the port C and force the piston to the other end of the cylinder. The steam from the previous stroke which is filling the cylinder on the opposite side of the piston must have some means of getting out. It passes through the port C′, under the slide valve D, and out through the central exhaust port J, to the air. During the next stroke the conditions will be reversed. The valve will have moved far enough over to cover port C and uncover port C′. Steam will now enter from the steam chest through the port C′, forcing the piston towards the left, while the steam from the previous stroke will escape through C, under the valve D, to J.

Steam which has not been used for developing power is called LIVE STEAM. Steam which has done its work and been allowed to escape is called EXHAUST STEAM. As it is necessary to prevent condensation, as far as possible, the engine cylinder is often enclosed with a covering of wood called lagging; in this way an air chamber is formed around the cylinder in which there can be no movement of air, and as air at rest is a non-conductor of heat, it prevents, to a great extent, condensation of the steam in the cylinder.

At the outer end of the piston-rod is the cross-head N. The object of this is to guide the end of the rod and to take up the strain due to the angularity of the connecting rod K. The cross-head consists of an iron block into which the end of the piston-rod is fastened

by threads or by means of a tapered joint and a wedge pin. The cross-head is kept in position by guides forming a part of the engine frame, and placed one above and one below the cross-head in the direction in which it receives the strain.

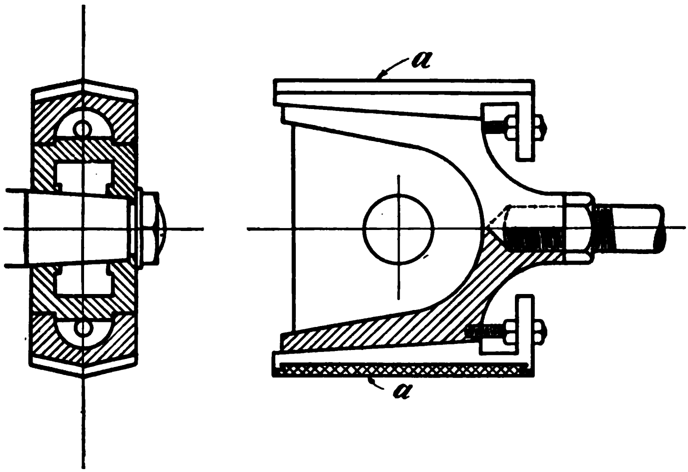


Fig. 4.

In order to prevent undue wear, the cross-head does not bear directly upon the guides, but a space between the two is filled by pieces of metal, called slippers, *aa*, Fig. 4, their bearing surfaces being composed of Babbitt or other anti-friction metal. These slippers are adjustable for wear so that they may be slightly tightened when necessary, in order to prevent the cross-head from running so loose as to be shaky, and yet not so tight as to prevent freedom of motion.

The cross-head pin T, Fig. 1, passes through one end

of the connecting rod K. The other end of the connecting rod rests on the crank pin U, which is fastened to the crank L. The opposite end of the crank is firmly fixed upon the crank shaft M.

The ends of the connecting rod F, Fig. 5, are made square. The strap B is fastened in place by a gib and

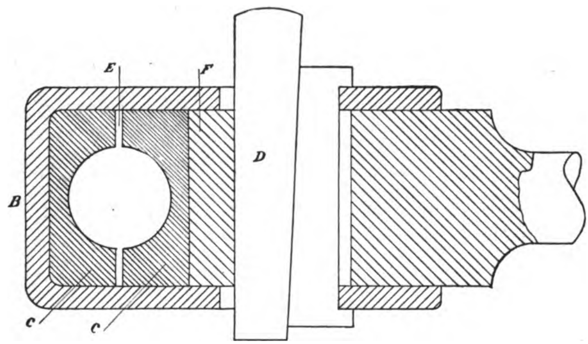


Fig. 5.

cotter leaving a space which is filled by two gun-metal blocks CC, called the brasses. These are tightened to the required amount by means of the wedge-shaped pin D, which, upon being driven down, draws in the strap B, tightening the brasses CC upon each other. When first made the brasses do not quite touch; but after having been adjusted for wear a number of times the edges may come in contact at E. It is then necessary to take them out and file off the edges in order to allow for drawing them still closer together. Adjusting the brasses at the ends of the connecting rod may in time produce a change in the original center distance of the two ends. It is then necessary to insert thin pieces

of metal between the ends of the connecting rod and the brass at F in order to restore the original length. These thin pieces of metal are called shims. A change in the center distance of the connecting rod would make no material difference in the operation of the engine were it not for the fact that a shortening of this rod would cause the piston to come a little closer to the front head of the engine at each stroke and in time would so reduce the clearance space as to cause the piston to strike the head, when serious damage would result.

The crank pin is usually shrunk into its place in the crank. This is done by turning the pin slightly larger than the hole in which it is to go, about one one-hundredth of an inch larger for each inch of diameter. The crank is then heated and the resulting expansion enables the pin to be slipped easily into position. As the crank cools its contraction causes it to grip the pin firmly.

When the piston is at the end of its stroke a line drawn through the center of the piston-rod would also pass through the centers of the cross-head, crank pin and shaft. The engine is then said to be on dead center and no matter how much pressure might be exerted on the piston there would be no tendency for it to move. When the crank has moved around to an angle of ninety degrees from the dead-center line, the point of maximum power is reached.

As the crank passes the dead centers at two points during each revolution, some means must be employed to help the engine over these points where little or no turning power is derived from the piston. A wheel with a heavy rim, called the FLY-WHEEL, placed on the

crank shaft, serves this purpose, for during that portion of the stroke when the greatest power is developed, a part of it is used in setting this wheel in motion. During the weakest portion of the stroke the momentum of the heavy fly-wheel restores some of this stored power to the shaft, thus helping to produce a regular and continuous motion.

When an engine is running so that a person standing at the cylinder end of it sees the crank pin move up and away from him it is said to be *over-running;* when the crank pin moves in the opposite direction the engine is said to be *under-running.*

When an engine is over-running the pressure on the piston, transmitted through the crank shaft to the crank pin and doing the work, tends to produce a downward pressure at the cross-head during the first part of the revolution. During the second part of the revolution the piston is pulling the crank pin towards the cylinder and a similar downward pressure is again exerted. If the engine were under-running the pressure on the cross-head would be in an upward direction, for similar reasons; thus, in the case of a stationary engine designed to run only in one direction, slides on both sides of the cross-head are not absolutely essential, but as conditions may occasionally require that the direction of operation of the engine be changed, and as the presence of both guides tends to stiffen and steady the engine frame, it is advisable that they be used. In case of marine, locomotive, hoisting, or similar engines, in which the direction of operation must frequently be changed, the guides on

both sides of the cross-head are a self-evident necessity. As the slide valve controls the admission of the steam which operates the piston, which, in turn, by means of a crank, changes its reciprocating movement into rotary motion at the main shaft, it is evident that some definite relation must exist between the movement of the piston and the slide valve. These are mechanically connected more or less directly according to conditions presented in the design of the engine. It is apparent that if a small crank were attached to the main shaft and this in turn connected to the slide valve, this second crank could be placed in such a position, relative to the main crank of the engine, that it would operate the slide valve and cause it to open and close at such times as would be required for the proper admission of steam. The building of such a crank, however, would make the engine commercially expensive and in some instances seriously weaken the shaft.

The same purpose is served in a far better way by the use of the eccentric.

QUESTIONS.

1. What is a steam engine?
2. Name the principal parts of a slide-valve engine.
3. Describe the piston.
4. Describe the cylinder of a slide-valve engine.
5. How are the cylinder heads fastened?
6. How is the piston made steam-tight?
7. How is steam prevented from leaking where the piston and valve rods pass out of the cylinder and steam chest?
8. How does the steam reach the cylinder from the supply pipe?
9. What is the cross-head and its use?
10. Sketch one end of the connecting rod.
11. What are the dead centers?
12. On which guide does the cross-head pressure occur?

CHAPTER II.

ACTION OF THE ECCENTRIC.

Imagine a pulley fitted on a shaft with a center hole concentric with its outer surface. When the shaft and pulley are rotated every point touched by the circumference of the pulley will at all times be the same distance from the center of the shaft.

In the eccentric, Fig. 6, the opening for the shaft

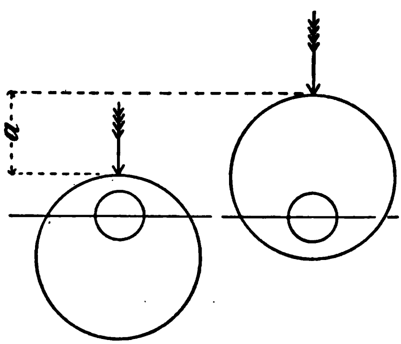


Fig. 6.

is drilled *out of center* in the pulley, and it may be readily seen that, as the shaft rotates, a point indicated by the arrow will, at some part of the revolution, be quite close to the shaft and at another at a distance away from it, represented by the larger radius of the eccentric.

The arrow, if its point were kept pressing against the

circumference of the eccentric, would have a movement equal to the difference, *a*, between the shorter and the longer radius.

This principle is taken advantage of in engine construction for operating the slide valve. The eccentric, Fig. 7, consists of a disc having a shaft hole drilled out

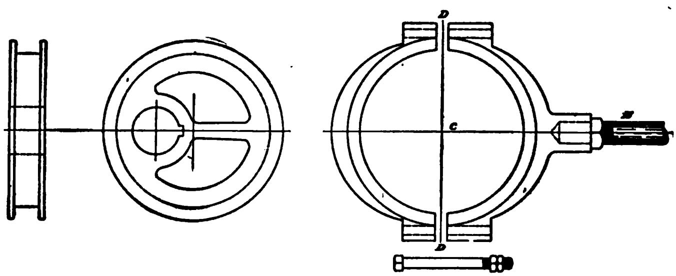


Fig. 7.

of the center, and a groove turned in its edge. In this groove is fastened the eccentric strap C, the two halves of which are fastened together by bolts at DD. The strap is free to swing easily in the groove and prevented from sliding off at the sides by the raised edges. When the eccentric is revolved by the turning of the main engine shaft, the eccentric rod E receives a movement similar to that of the arrow in the previous illustration.

The eccentric rod is sometimes directly connected to the valve rod O, Fig. 1, shown passing through the walls of the steam chest, leakage being prevented by a stuffing box similar in construction to that described in connection with the piston rod.

On other engines it is necessary to interpose a rocker arm F, Fig. 8. In this case the rocker arm F, pivoted at

G to some suitable point of the engine frame, is also pivoted to the eccentric rod, as shown, and receives movement from it, which movement is imparted to

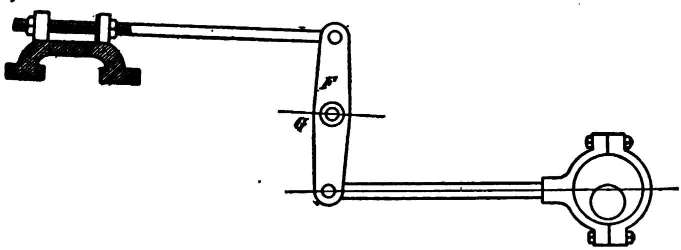


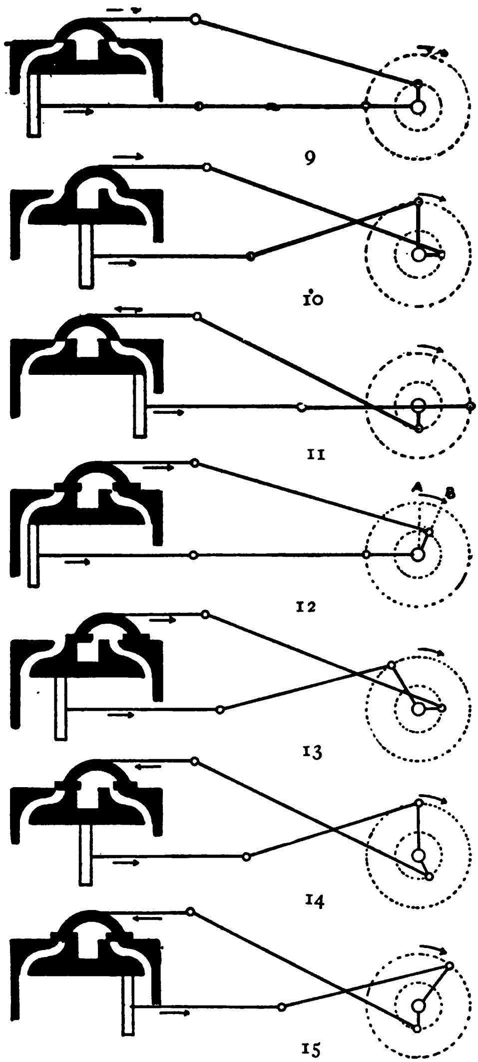
Fig. 8.

the valve rod, at its upper end, and through this to the slide valve itself.

The distance from the center of the hole in the eccentric to the true center of the eccentric disc is called the *radius of the throw*. The throw of the eccentric is equal to twice this radius or the diameter of a circle whose radius is the distance between the eccentric and the concentric centers.

In Figs. 9 to 15 are shown a number of diagrams illustrating the action of the eccentric in controlling the movements of the slide valve relative to the position of the piston at various points of the stroke and also indicating the necessity for the presence of LAP on a slide valve in producing economical operation of a steam engine. All of the diagrams show the piston moving forward on the same stroke. The position of each of the moving parts is indicated by the arrows.

In Fig. 9 the piston is at the beginning of its stroke, and the plain slide valve, without lap or lead, is shown



Figs. 9–15.

just ready to open the port and allow the admission of steam. Reference to the circles at the right-hand side of the diagram will show that the small crank, representing the eccentric, is placed at right angles to the main engine crank. When the piston has reached one half of its stroke, Fig. 10, the engine crank is vertical, the eccentric is horizontal, and it has brought the valve over as far as it will go during that stroke. The steam port is shown completely opened as well as the exhaust port. When the piston has continued to the end of the stroke, Fig. 11, the position of the crank has been advanced one fourth of a revolution. The piston, connecting rod, and crank are again on dead center and the slide valve has again closed both ports, while the one on the right-hand side is just ready to open for the return stroke. It is clearly seen that with such a construction there can be no cut-off and no expansion of steam. The steam must, of necessity, follow during the entire stroke and cannot be cut off previous to the end of the stroke, for if the position of the eccentric crank were such as to allow the valve to close one steam port before the end of the stroke, it would, at the same time, open the opposing port for the admission of steam. In Fig. 12 there has been added to the valve, both inside and outside, an amount of material producing the LAP, and the valve and piston are placed as before, the valve being barely opened in order to allow the admission of steam to the cylinder. We find that the eccentric crank has been advanced in the direction of rotation an amount represented by the angle between its original point, as shown by the dotted

line A, and its present position as shown at B. This amount is called the *angular advance* of the eccentric and is equal to the amount required by the lap and the lead. As the engine rotates and the piston has reached its quarter stroke, Fig. 13, the steam port is entirely opened, as is also the exhaust port, allowing a free exhaust. On reaching the half stroke, Fig. 14, it will be noticed that the valve is now traveling in a direction opposite to that of the piston and that the port has just been closed. Consequently, from this point on during the remainder of the stroke the piston will be propelled by the expansive force of the steam only. At three quarters of the stroke, Fig. 15, both ports are shown closed. The piston is still moving forward, due to the expansion, and the exhaust now being closed, compression is taking place and will continue during the remainder of the stroke. At the end of the stroke the conditions shown in Fig. 12 will again exist, but, of course, in the reverse direction.

From the foregoing it will be noted that with lap added, with the piston on center, and all parts moving forward, it is necessary to give the eccentric sufficient angular advance to produce the required lead at the beginning of the stroke. It will also be seen that increasing the outside lap will allow of cutting off steam at an earlier period of the stroke, thereby increasing the expansion, while decreasing the outside lap produces reverse results.

It may also be noted that the addition of inside lap to the exhaust valve causes an earlier closing of the exhaust valve, therefore increased compression. This

also would delay the release of exhaust steam. Consequently in designing an engine, the amount of lap, both inside and outside, must be carefully considered in their relation to the general periods of cut-off, expansion, and compression.

As the eccentric, in the position shown, controls the valve in such manner as to admit steam as required to produce a forward movement of the engine, a little thought will make it clear that in order to operate the engine in the opposite direction, it will be necessary to place the eccentric in a reverse position. It is inconvenient to do this while the engine is in operation. On locomotive, marine, or similar engines, two eccentrics are employed. One is set in the proper position for operating ahead, the other is in a position for reverse. These are placed in active operation in connection with the valve rod by means of a link motion, Fig. 16, so arranged that when the link is in the central

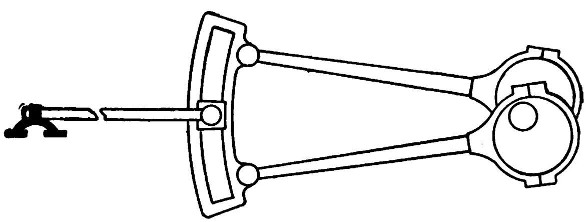


Fig. 16.

position neither eccentric has any control over the valve movement. But when one or the other is shifted into position by the link, it changes the valve position so as to enable the engine to run forward or backward, as desired.

As the steam must be ready to propel the piston as soon as it passes the dead center, or the beginning of the stroke, the lap of the valve enables us to open the port slightly before the beginning of the stroke, likewise to close it before the end of the stroke.

LAP represents the part added to the valve which makes it wider than the port opening.

LEAD represents the space the valve is open when the piston commences to move forward.

VALVE TRAVEL is the distance the valve moves during the stroke.

The TRAVEL of a slide valve equals the outside lap plus the width of the steam port multiplied by two.

CLEARANCE. — This is the space between the piston and the head of the cylinder at the end of the stroke. It also includes the volume of the steam passages or ports between the cylinder and the valves. To a certain extent clearance is a drawback on account of the quantity of steam which occupies the space; still, on the whole, it is an advantage, for when steam is used expansively, the steam in the clearance space expands as well as the rest, and adds slightly to the power developed. A convenient method of measuring the clearance volume is to place the piston at the end of the stroke, fill the clearance space with water, and, drawing it off in a measure, calculate its volume in cubic inches.

STEAM JACKETING. — As it is an advantage to maintain a constant temperature in the engine cylinder in order to avoid condensation, the engine casting is so made that the cylinder proper is enclosed in an external shell thus forming an annular space between the outer

shell and the cylinder which is filled with steam. Such a construction is called a steam jacket.

WIRE DRAWING. — When the main valves are not sufficiently large or are partly closed, so that the steam does not enter with sufficient rapidity to maintain the pressure behind the piston, it is said to be wire drawn.

RELIEF VALVE. — Some condensation of steam may take place in the cylinder at any time, also water may be carried into the cylinder with the live steam; and, particularly when starting an engine cold, after a period of rest, condensation is likely to take place. To enable us to get rid of this water, relief or drain valves are connected to the engine cylinder and are opened by the engineer for a short time, usually on starting. After the engine is warmed up they are again closed to prevent any excessive escape of steam. As water is practically incompressible, should a quantity collect in the cylinder serious damage might be caused. When an engine is operating under such conditions that this is apt to occur, relief valves similar in form to spring safety valves are sometimes placed in the cylinder head. These will provide means of escape for the water without injury to the engine.

QUESTIONS.

1. How is the slide valve operated?
2. Sketch and describe the eccentric.
3. What is the travel of a valve?
4. What is meant by lap and lead?
5. What is the angular advance of the eccentric?
6. What effect has the angular advance of the eccentric on the running of the engine?

7. Define clearance; steam jacketing; wire drawing of steam.

8. What is a relief valve?

9. How may the direction of rotation be changed?

10. What is the travel of a valve?

11. If the eccentric center is offset 2 inches, what will be the length of the valve travel?

CHAPTER III.

THE GOVERNOR.

If the eccentric is considered as a small crank, fastened to the engine shaft by means either of a key or set screw or both, it may be so adjusted relative to the main crank that its action transmitted through the various rods will open the inlet port into the cylinder just before the piston is ready to start on the forward stroke, thus admitting a supply of steam.

It is evident that a given quantity of steam will do but a certain amount of work. If the engine is running at a certain speed with a certain load and a greater number of machines are put on or the load increased in any way without varying the amount of steam supplied, or if, on the other hand, the load is decreased and the same quantity of steam is allowed to enter the cylinder, it is readily seen that the engine will slow down in the first instance and increase in speed in the second.

It is necessary, therefore, to change the quantity of steam delivered to the cylinder in accordance with the work that the engine is called upon to do at any given time. For this purpose a governor is employed.

The principle of the governor is as follows:

Let us assume a vertical rod *a*, Fig 17, connected to the main shaft of the engine by means of a belt operating through a pulley and two beveled gears *p* and *p*,

so that the rod *a* revolves at the same speed as the engine shaft. Suspended from pivots in a block *c* at

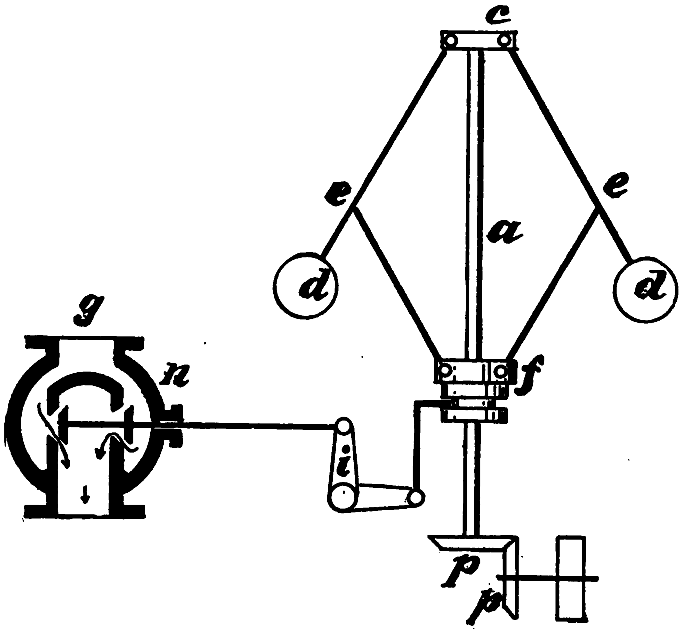


Fig. 17.

the upper part of rod *a* are two rods *e*, *e*, on the extremities of which are fastened the weights *d*, *d*.

In accordance with the well-known principles of centrifugal force and gravity, as the rod *a* increases or decreases in speed, the weights *d*, *d* will rise or fall. Pivoted at *e*, *e* are two rods also pivoted to the collar *f*, which is free to rise and fall upon the rod *a*. Any change in speed of the engine shaft will cause a corresponding change in the speed of the rod *a*, also a change

in the position of the weights *d*, *d* and in the vertical position of the collar *f*. If now the main steam pipe *g*, supplying the engine, be considered as having a valve at *n*, the valve rod being connected to the bell crank *i*, which in turn is pivoted to the collar *f*, it will be seen that as the speed of the engine increases, due to a decrease of load, the collar *f* will rise and, through the various levers and the valve *n*, will partially close the opening of steam pipe *g*. On the other hand a decrease in speed, due to an increase of load, will cause the collar *f* to drop, thereby opening the valve *n*. In the one case less steam will be admitted to the cylinder and in the other, more, thus providing for the change of load, and maintaining a constant speed of the engine.

An engine governor is constantly in operation, changing with the load. A governor of this type is called a THROTTLING GOVERNOR. The pivoted rods may be replaced by springs serving the same purpose. Its disadvantage is that the steam admission is regulated at a point some distance from the cylinder in which it is used. Consequently the regulation of the engine is not as close as might be desired. An improvement upon this type is that of the Corliss engine, a description of which will be given later.

The previous illustration of the governor is correct in principle, but it is merely a general description of the governor action and its application to the regulation of steam engines by varying the supply of steam to meet the conditions existing at any given time. Governors vary in detail of construction with almost every make of engine. They are all built, in general, along

similar lines and operate on the principles of throttling and automatic cut-off. In the former case, as already mentioned, the operation takes place at some little distance from the cylinder, in consequence of which the action is slow and not sufficiently sensitive for high speed or economical work. Modern practice in this line has made it necessary to bring the action of the governor as close to the cylinder as possible and preferably to have it operate directly on the steam valve, the length of ports between the valve and the cylinder being made as short as possible. An excellent illustration of this type is that of the Corliss engine, Fig. 64, where two steam valves, one at either end of the cylinder, are immediately controlled by the governor. In case of a slide-valve engine, as illustrated in the diagram showing its action, Fig. 15, a somewhat different problem is presented, due to the fact that under certain conditions close regulation of the valve would not allow sufficient opening to introduce the required quantity of steam into the cylinder. This difficulty is overcome by what is called the riding cut-off. In this instance the valve and ports are allowed a generous opening for the admission of steam and two eccentrics are employed, one being permanently located in position and regulating the general movement of the valve for the admission of steam, and the other being a movable eccentric, the position of which may be varied by the governor. This second eccentric controls a secondary valve riding on top of the slide valve proper and serving to cut off the steam at the required moment.

The automatic type of governor, according to its

position, may be divided into two classes, namely: A *fly-ball* or *pendulum governor*, and the *shaft governor*. In these cases the centrifugal force, due to revolving a weight around a central pivot, is the operating power.

In the fly-ball governor, similar in general construction to the illustration previously given, the weights and rods, by which they are suspended, form a cone. The path through which they move is called the cone of revolution. When the governor is revolving about its axis at a constant speed the weights revolve in a circle, having the radius r, Fig. 18. The distance from this plane

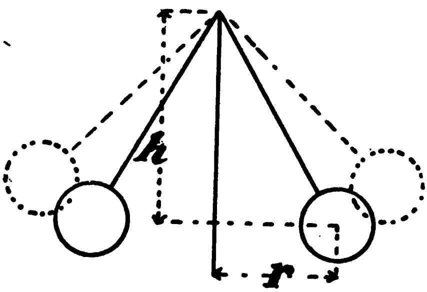


Fig. 18.

to the intersection of the rod is called the height and is equal to h. If the balls revolve fast, the centrifugal force increases, r becomes greater, and h diminishes.

The centrifugal force is expressed by the formula $F = \dfrac{Wv^2}{gr}$; that is, the centrifugal force varies directly as the weight of the balls and the square of their velocity; and inversely as the radius.

While the pendulum is revolving, centrifugal force

acts horizontally outward and tends to make the ball fly from the center; gravity tends to make the ball drop downward.

From certain mathematical calculations it is determined that the height *h*, Fig. 18, is independent of the weight of the balls or the length of the rod; it depends upon the number of revolutions.

The height varies inversely as the square of the number of revolutions.

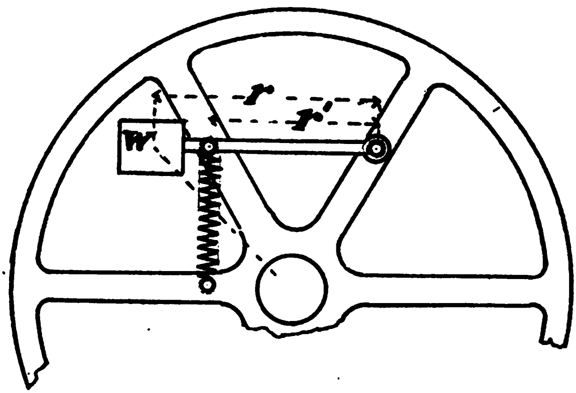


Fig. 19.

As the speed increases the cone becomes shorter because the weights rise. A constantly increasing speed would produce a relatively diminishing height of cone.

Such a governor is too sensitive for high-speed engines. When, however, it is desired to employ such a governor for fairly high speed, weights are added to the spindle, usually above the collar *f*, Fig. 17.

SHAFT GOVERNORS, as their name implies, are fastened directly to the shaft, or to some connecting part, and revolve with it. They are of two general forms, known as *centrifugal* and *inertia* governors.

The principle of the first type is illustrated in Fig. 19. An arm whose length is r is pivoted at some point on the fly-wheel, having attached to it a weight w. At a distance r' from the pivot a spring is attached so as to act at right angles to the arm.

The centrifugal force of the weight, when the engine is running, will be balanced by the pull of the spring and the pull on the arm. But as the latter acts directly through the supporting pivot it may be neglected. When the engine increases in speed, the weight is thrown out toward the rim of the wheel and, by means of a lever through which it is connected to the eccentric, it shifts the eccentric's position so as to produce an early cut-off. Remember that the amount of valve travel is governed by the throw of the eccentric, which, in turn, depends upon the distance out of the true center that the shaft hole is bored in the eccentric. Also bear in mind that were this hole in the true center, the eccentric would impart no movement to the slide valve.

The INERTIA GOVERNOR, Fig. 20, consists essentially of a bar with a weight at either end pivoted at the pin c. A spring d tends to hold the weights and the bar in the starting position against the stop e. The eccentric rod is connected to the pin f which takes the place of the eccentric. As the speed increases, the centrifugal force of the weights is increased until it overcomes the tension of the spring d, and the bar swings about its

supporting pivot *c*, changing the position of the pin *f* relative to the center of the shaft, and producing the same effect as was produced by the shifting of the eccentric in

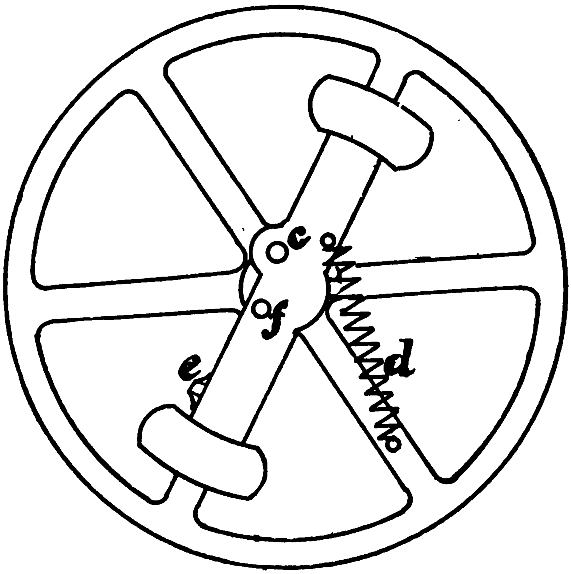


Fig. 20.

the previous description. If there should occur a sudden change of load the weights will tend for a moment to continue ahead at the same speed at which they were traveling. They may, therefore, run ahead or lag behind. The result of this action is to change the position of the eccentric pin in its relation to the center of the shaft. In such a governor the inertia of the cross bar and weights materially supplements the centrifugal force and increases its sensitiveness.

QUESTIONS.

1. How is the speed of an engine controlled?
2. Make a sketch embodying the principles of governor operation.
3. What objection is there to the throttling governor?
4. In a pendulum governor, what effect has the speed of rotation on the position of the weights?
5. What effect has the weight of the balls on the height?
6. How does the height vary?
7. What is a shaft governor?
8. Name two forms of shaft governors.
9. Describe a centrifugal governor.
10. Describe an inertia governor.

CHAPTER IV.

ENGINE CALCULATIONS.

The horse power of an engine is calculated on the basis of a period of one minute of time. One mechanical horse power equals 33,000 foot pounds of work done in one minute.

If, for example, a certain engine is doing 33,000 foot pounds of work and is requiring two minutes' time to do that work, it is working at the rate of one half of one horse power. If it does the work in thirty seconds or one half minute, it will then be able to do twice the work in one minute and is working at the rate of two horse power.

In the steam engine we may determine the horse power, providing we know the pressure of steam, area of the piston, and the number of feet through which the piston travels per minute. The distance that the piston travels from one end of the cylinder to the other is called the stroke. The diameter of the cylinder, which equals the diameter of the piston, and the length of the strokes are usually given in inches.

The pressure of the steam is given in pounds per square inch and it should be remembered that there are two strokes per revolution. With these facts in mind we may lay down the following rule:

The pressure of steam per square inch times the number of square inches in the area of the piston equals the total weight or load to be carried.

Twice the number of revolutions multiplied by the length of the stroke in feet equal the distance through which the load is to be carried. The length of the stroke is calculated in feet, as we are determining the number of *foot pounds* of work. ***Then, the total load times the distance through which it is carried in one minute equals the number of foot pounds.*** In reducing this to a convenient formula, we have the following:

$$\frac{\text{PLAN}}{33{,}000} = \text{H.P.}$$

In the formula the pressure on each square inch is indicated by the letter P, the length of the stroke in feet is indicated by the letter L, the area of the piston in square inches by the letter A, and the number of strokes per minute by the letter N. The number of foot pounds per horse power is indicated by the figures 33,000.

Find the horse power of an engine whose cylinder is ten inches in diameter, the length of stroke two feet, the pressure per square inch fifty pounds, with engine making one hundred revolutions per minute.

$$\frac{\text{PLAN}}{33{,}000} = \frac{50\,(\text{lb.}) \times 2\,(\text{ft.}) \times 78.5\,(\text{sq. in.}) \times 200\,(\text{strokes})}{33{,}000\,(\text{ft. lb.})}$$

$$= \frac{1{,}570{,}000\,(\text{ft. lb.})}{33{,}000} = 47 + \text{H.P.}$$

The diameter of the cylinder and the length of stroke are expressed in inches. An engine having a cylinder twelve inches in diameter and a stroke of two feet would be written 12″ × 24″.

When the exhaust steam is allowed to escape directly to the atmosphere, after having been used in the engine cylinder, the engine is said to be running *non-condensing.*

In some cases the exhaust steam is run to a condenser and after having been condensed is sent to the boiler to be used over again. Such an engine is of advantage because the use of the condenser enables us to produce a partial vacuum on the one side of the piston. The reduction of pressure thus obtained is an immediate gain in power. When the steam enters one side of the cylinder, let us say at a pressure of one hundred pounds per square inch, this is not entirely available in producing work. Some of it is used in doing the work necessary to overcome friction in the engine itself. Some more of it is required to force the exhaust steam out into the air if it is a non-condensing engine; the exhaust steam offers resistance, because in order to get out of the cylinder it has to displace the atmospheric air; also considerable friction is produced in passing through the pipes, fittings, valves, and other obstructions which it meets between the cylinder and the outer air. This resistance is called *back pressure*, and the amount of work required to overcome this back pressure must be subtracted from the pressure of the steam entering the cylinder in order to determine how much we have left as *effective pressure* to do the external work. If, for instance, the back pressure, due to friction in the pipes, etc., plus that due to the atmosphere equals seventeen pounds per square inch and the pressure entering the cylinder equals one hundred pounds per square inch,

then seventeen of the original one hundred pounds must be used to overcome the back pressure, leaving us only eighty-three pounds as actual effective pressure to do the external work.

If the engine is connected to a condenser and, instead of exhausting steam direct to the atmosphere, exhausts it to the condenser where it is changed into water, the volume of this water will be far less than the volume of steam which formed it. Consequently a partial vacuum will be formed on the exhaust side of the piston and the back pressure will fall from the previous seventeen pounds per square inch to perhaps seven pounds per square inch, giving us a total gain in effective pressure of ten pounds per square inch, and if the piston has an area of one hundred square inches, a gain of ten pounds per square inch will equal a total pressure of one thousand pounds.

In the early days of engineering, when low-pressure steam was used, it was customary to carry the pressure during the entire length of the stroke. Modern practice, however, proves that it is more economical and that greater efficiency is developed by using steam of higher initial pressure. We can thus take advantage of the expansive power of the steam by closing the inlet valve at some early period in the stroke. This will allow the work, during the remainder of the stroke, to be done entirely by the expansive force of the steam.

QUESTIONS.

1. What is a mechanical horse power? (H.P.)

2. What must be known in order to calculate the horse power?

3. Give the formula for the calculation.

4. Find the H.P. of a 10″ × 12″ engine making 250 revolutions per minute with a pressure of 45 lb. per sq. in.

5. Find the H.P. of a 12″ × 25″ engine making 90 revolutions per minute with an average pressure of 50 lb. per sq. in.

6. If, in the previous question, it is desired that the engine should develop 75 H.P., what change could be made?

7. A 20″ × 36″ engine has 40 lb. M.E.P. (mean effective pressure) and 60 revolutions per minute; required to find the H.P. developed.

8. If the above engine were required to develop 175 H.P., what change in pressure should be made, the other conditions being allowed to remain?

9. If the change were required to be made by increasing the number of revolutions, how many would be necessary?

10. If an engine were required to develop 175 H.P. at 60 revolutions, M.E.P. of 40 lb., a stroke of 3 ft., what should be the diameter of the cylinder?

11. In the previous question, what would be the capacity of the cylinder if 6 per cent were allowed for clearance?

12. If 0.45 lb. of steam per stroke were used, what weight of steam per hour would be required at 200 revolutions?

13. What is a non-condensing engine?

14. Define back pressure.

15. What is the effect of back pressure on the operation of the engine?

CHAPTER V.

THE PISTON.

PISTON SPEED is the distance through which the piston travels during one minute. It is not at the same rate as the crank pin for the reason that, although mechanically connected together, the crank pin moves along the circumference of a circle while the piston moves a distance equal to the circle's diameter. Bearing in mind that the crank pin moves along one half of the circumference of the circle for each stroke, the ratio of movement is

$$\text{Crank-pin speed : piston speed} :: \frac{3.1416}{2} : 1, \text{or } 1.5708 : 1.$$

With a mean piston speed of 1000 feet per minute we have $1000 \times 1.5708 = 1570.8$ feet per minute as the mean crank-pin speed.

As the work done on both pin and piston is the same while the speed of the pin is 1.5708 times that of the piston, then the mean pressure on the crank pin is $\frac{1}{1.5708}$ of that on the piston.

PISTON DISPLACEMENT, or volume swept by the piston, is equal to the area of the cylinder times the length of the stroke, and equals the amount of steam displaced by the piston during one stroke.

The pressure on the cross-head exerted through the connecting rod and crank pin causes a strain on the guides which varies throughout the stroke, and varies

on different engines according to the angle taken by the connecting rod. This angularity of the connecting rod on any individual engine depends on the length of the rod itself, for a short rod would, evidently, at some point produce an angle more nearly approaching a right angle than would be possible if the rod were of two or three times its length. The length of the connecting rod must not be too long, however, both on account of the space it would require and because a long rod would be flexible and mechanically weak.

To determine the pressure or thrust on the guide we may use the following formula:

Maximum thrust =

$$\frac{\text{pressure on piston} \times \text{radius of the crank in inches}}{\text{length of the rod in inches}}.$$

The RADIUS OF THE CRANK is measured from the center of the crank shaft to the center of the pin.

The diameter of the circle described by the crank pin is equal to the stroke of the engine and its radius is sometimes called the THROW.

The portion of the total pressure on the crank pin which turns it about the shaft center is called the TANGENTIAL PRESSURE.

If the circumference of the circle, Fig. 21, represents the path of the crank pin, then at the points *a* and *e*, or the dead centers, no turning effort is produced. But with the pin at *c* the turning effort is wholly expended in turning the shaft, and is equal to the line *cb* drawn to any convenient scale. The turning or tangential pressure varies from nothing at *a* to maximum at *c*.

Considering the connecting rod to be of indefinite length and neglecting the weight of the parts, to ascer-

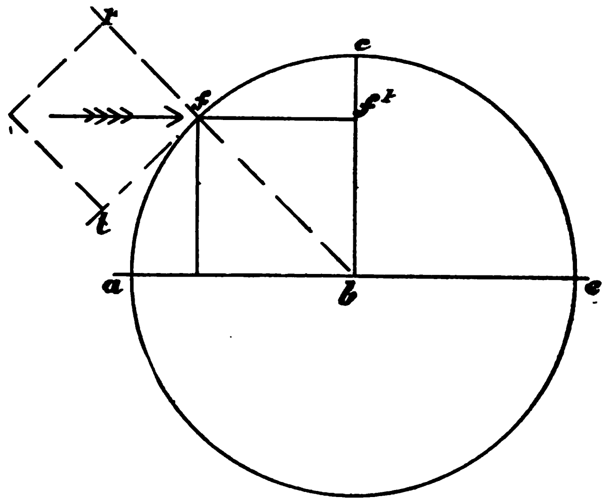


Fig. 21.

tain the pressure at any point as *f*. Through *f* draw the line *ff'* parallel to *ab*, resolve it into a parallelogram of forces, as shown, and the tangential line *tf* will represent the portion of the force *cb* used in turning the shaft, and *fr* will show the amount of force pressing on the bearing.

BRAKE TEST.

Two methods of determining the horse power of a steam engine are illustrated in the rules given for calculating the H.P., and in the method of obtaining results from an indicator diagram. Still another method is often convenient: namely, by obtaining the brake H.P.

This requires the use of an apparatus called the *prony brake,* and the term *brake horse power* is used to represent the power actually developed by an engine under such a test. These pieces of apparatus vary in design. The simple application, illustrating the principles involved, is shown in Fig. 22. Upon the fly-wheel

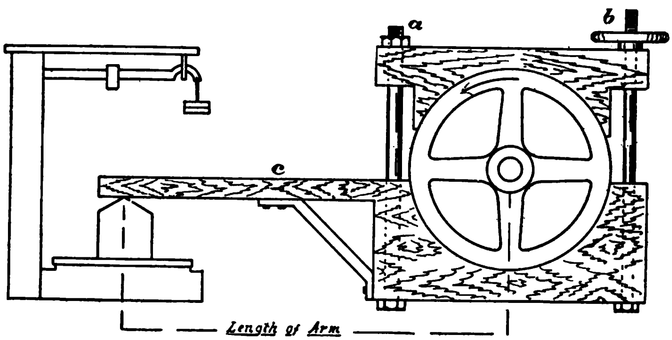


Fig. 22.

or pulley fastened to the main shaft is clamped a brake consisting of two wooden pieces lined with some material which may be saturated with water, in order to keep the pulley and brake from over-heating. It is provided, through the bolt *a* and the hand-wheel and bolt *b*, with a means for readily adjusting the tightness by which the pulley is held. The power arm of the brake *c* rests on a pivot placed on a scale. Supposing the engine to be rotating in the direction of the arrow and the hand-wheel tightened until any further tightening would reduce the speed below the normal running speed, then if the revolutions per minute and the weight registered by the scale be taken, the length of the brake arm being known,

we have the necessary items to determine the brake H.P., at this speed. If, for example, the length of the brake arm is 5 feet 3 inches, and the end resting on the scale weighs 3 pounds before tightening the hand-wheel, and if the engine is running at the required speed, with the weight registering 38 pounds, there remains 35 pounds as the actual pull or force exerted by the engine.

Supposing the revolutions to be 1000 per minute, and the brake arm were free to revolve, the extremity of the arm would describe a circle 10 feet and 6 inches in diameter, or 33 feet in circumference, and, as shown on the scale, it would have a pressure or pull of 35 pounds. Therefore, on the same principle as before, the H.P. equals the weight times the distance divided by 33,000. We then have the following result:

$$\frac{33 \times 1000 \times 35}{33{,}000} = 35 \text{ B.H.P.},$$

or the brake horse power at this particular speed.

THE FOOT POUND IS THE UNIT OF MECHANICAL WORK. The foot pound represents the amount of work required to lift a weight of one pound one foot high.

THE HORSE POWER IS THE UNIT OF POWER.

33,000 FOOT POUNDS EQUAL ONE HORSE POWER.

To determine the horse power we must note the number of foot pounds of work done in a given time.

QUESTIONS.

1. What is piston speed?

2. What is piston displacement?

3. What is the angularity of the connecting rod?

4. What effect has the angularity of the connecting rod on the crank pin?

5. How may the maximum thrust on the guides be determined?

6. What is the crank radius?

7. What is tangential pressure?

8. What will be the mean pressure on the crank pin of an engine 24 in. in diameter, 36 in. stroke, 45 lb. M.E.P.?

9. In an engine having a cylinder diameter of 36 in., a stroke of 24 in. and a mean pressure of 50 lb., what is the mean pressure on the crank pin?

10. How may the brake horse power be determined?

11. Find the B.H.P. of an engine making 250 revolutions with a scale pressure of 100 lb. and a brake arm 3 ft. long, the weight of the arm being 5 lb.

CHAPTER VI.

WORK DONE BY STEAM DURING FORMATION.

Let us assume a vessel in which we have placed one pound of water at a temperature of 32° F., and resting upon the surface of the water is a piston and a weight which together represent the pressure of the atmosphere. If we apply heat to the vessel the water will become heated and the temperature will continue to rise until the thermometer registers 212° F. If now the application of the heat be continued, steam begins to form. As it forms, the piston rises and continues to rise during the formation of the steam. The thermometer, however, does not indicate any change in the temperature during this time. Finally a point is reached when the last drop of water has been transformed into vapor. This vapor is called SATURATED STEAM. If the application of heat is still further continued we will produce SUPERHEATED STEAM, the temperature of which will rise according to the continued application of heat and will perform additional work by lifting the weight to a greater height. Now, if the vessel is of considerable height and has an area of 1 square foot equal to 144 square inches, as 1 cubic foot of water weighs 62.5 pounds, 1 pound of water placed in such a vessel will stand $\frac{1}{62.5}$ or 0.016 of a foot high. As the weight of the atmosphere at the sea level equals 14.7 pounds per square inch, there will be

upon the surface of the water in this vessel a weight equal to 14.7 pounds per square inch or a total weight of 14.7 times 144, equal to 2116.8 pounds.

Starting with a temperature of 32° and applying heat to it as before until the thermometer registers 212°, at which point formation of steam begins, we find that we have added to the water the difference between the two amounts, or 180 heat units, which amount is required to raise the water to the point where the formation of steam begins.

A HEAT UNIT (H.U.) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit, taken at its greatest density, about 39° F.

Continuing now the application of heat as before, until the water has been entirely changed into steam, we find that the piston has risen to such a point that at the moment when the water has all become steam it occupies the volume of 26.36 cubic feet. The total H.U. required to produce this change were 1146, of which 180, we have previously noted, were required to raise the water to steaming point and the remaining 966 to effect the molecular transformation of water into steam. During the second portion of this experiment no rise in temperature has been observed on the thermometer and yet we know that heat has been delivered to the water in order to effect the transformation. The heat measured during the first portion of the experiment is called SENSIBLE HEAT. That absorbed during the second portion, but not showing on the thermometer, is called LATENT HEAT. This latent heat, 966 H.U., served two purposes.

First, to change the water into steam.

Second, to do external work by lifting the weight pressing upon the surface of the water. If the weight or piston equals 2116.8 pounds and we have raised it 26.36 feet, this will equal 55,799 foot pounds.

Now, as we have seen that the application of heat will produce work, there must be some relation between heat and work, — between a certain amount of heat and a definite amount of work produced, which is expressed in foot pounds.

Referring to the definition of H.U., which is the amount of heat required to raise the temperature of one pound of water 1° F., taken at its greatest density, about 39° F., experiment has shown that ONE H.U. EQUALS 778 FOOT POUNDS OF WORK.

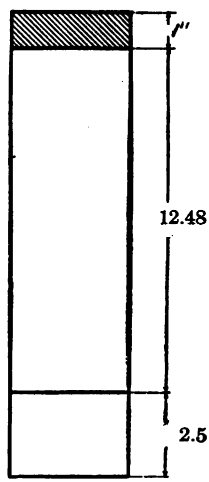


Fig. 23.

This being the case, we find that to do the 55,799 foot pounds of work previously mentioned 55,799 ÷ 778 or 71.72 H.U. were required. The balance of the 966 H.U. used in changing the water into steam, or 894.28 H.U., was used in doing external work.

Now, if we divide these figures, 71.72, 894.28, and 180, respectively by the smaller, we obtain the ratio of 1 : 12.48 : 2.5, which ratio expresses the respective proportion of the total 1146 H.U.

To illustrate this graphically let us draw a rectangle, Fig. 23, according to these ratios. We will note then

that the external work is the small shaded area at the top. It is self-evident that the external or useful work done by the steam is a very small part of the total work, and as the efficiency equals the area of external work divided by the total area we get:

$$\text{Efficiency} = \frac{\text{area of external work}}{\text{total area}} = \frac{1}{16} \text{ or only } 6.25\%.$$

Therefore, neglecting all other losses, which are considerable, in actual practice only the heat from 125 pounds of coal per ton will produce useful work.

If, instead of raising the steam to the pressure of 14.7 pounds per square inch as in the previous instance, we increase the pressure to 100 pounds per square inch, on referring to a table of saturated steam we find that one pound of steam at this pressure of 100 pounds per square inch occupies a volume of only 4.33 cubic feet. Employing the same vessel as before for changing the water to steam, one pound of water when changed to steam will then equal 100 pounds pressure times 144 square inches times 4.33 equals 62,352 foot pounds, while one pound of steam at atmospheric pressure we found equals 55,799 foot pounds, thus showing a balance in favor of the high pressure of 7553 foot pounds.

To produce the 100 pounds pressure, however, there was required a total heat of evaporation of 1181.91 H.U., while for the steam at atmospheric pressure there were required 1146.6 H.U., or 35.31 H.U. more for the high than for the low pressure.

To find the work done per pound of water during the formation of steam without expansion, we have the following rule:

Volume per pound times pressure per square inch times 144 equals foot pounds.

The volume per pound is found by referring to the saturated steam table.

EXAMPLE. — Find the external work done by one pound of steam at 50 lb. pressure, the volume at this pressure being 8.31 cu. ft.

SOLUTION. — 8.31 × 50 × 144 = 59,832 ft. lb.

AS ONE HORSE POWER IS EQUAL TO 33,000 FOOT POUNDS OF WORK IN ONE MINUTE, and in one hour we have 60 minutes, then during one hour one horse power will produce 33,000 times 60 or 1,980,000 foot pounds. Then using the result obtained in the previous example we have:

$$\frac{1{,}980{,}000}{59{,}832} = 33.09$$ **pounds of water required to produce one H.P. for a period of one hour.**

Reference to the table shows that very little more heat is required to produce high-pressure than low-pressure steam with equal weights of water; but if equal volumes of steam are used, this will not be true, for while 100 pounds of steam per square inch will exert twice as much pressure on the piston as 50 pounds per square inch, yet twice the volume of steam will be required. Therefore, in modern steam practice advantage is taken of the expansive force of steam to produce economical operations.

TABLE OF PROPERTIES OF SATURATED STEAM.

Pressure in pounds per square inch in above vacuum.	Temperature in degrees Fahrenheit.	Amount of heat in liquid over 32° in heat units.	Heat of vaporization, or latent heat in heat units.	Total heat of water in heat units above 32°.	Density or weight of a cubic foot of steam in pounds.	Volume of 1 pound weight of steam in cubic feet.	Pressure in pounds per square inch above vacuum.
1	101.99	70.0	1043.0	1113.1	0.00299	334.5	1
2	126.27	94.4	1026.1	1120.5	0.00576	173.6	2
3	141.62	109.8	1015.3	1125.1	0.00844	118.5	3
4	153.09	121.4	1007.2	1128.6	0.01107	90.31	4
5	162.34	130.7	1000.8	1131.5	0.01366	73.21	5
6	170.14	138.6	995.2	1133.8	0.01622	61.67	6
7	176.90	145.4	990.5	1135.9	0.01874	53.37	7
8	182.92	151.5	986.2	1137.7	0.02125	47.06	8
9	188.33	156.9	982.5	1139.4	0.02374	42.12	9
10	193.25	161.9	970.0	1140.9	0.02621	38.15	10
14.7	212.00	180.9	965.7	1146.6	0.03794	26.36	14.7
15	213.03	181.8	965.1	1146.9	0.03826	26.14	15
20	227.95	196.9	954.6	1151.5	0.05023	19.91	20
25	240.04	209.1	946.0	1155.1	0.06199	16.13	25
30	250.27	219.4	938.9	1158.3	0.07360	13.59	30
35	259.19	228.4	932.6	1161.0	0.08508	11.75	35
40	267.13	236.4	927.0	1163.4	0.09644	10.37	40
45	274.29	243.6	922.0	1165.6	0.1077	9.287	45
50	280.85	250.2	917.4	1167.6	0.1188	8.314	50
55	286.89	256.3	913.1	1169.4	0.1299	7.696	55
60	292.51	261.9	909.3	1171.2	0.1409	7.097	60
65	297.77	267.2	905.5	1172.7	0.1519	6.583	65
70	302.71	272.2	902.1	1174.3	0.1628	6.143	70
75	307.38	276.9	898.8	1175.7	0.1736	5.762	75
80	311.80	281.4	895.6	1177.0	0.1843	5.426	80
85	316.02	285.8	892.5	1178.3	0.1951	5.126	85
90	320.04	290.0	889.6	1179.6	0.2058	4.859	90
95	323.89	294.0	886.7	1180.7	0.2165	4.619	95
100	327.58	297.9	884.0	1181.9	0.2271	4.333	100
105	331.13	301.6	881.3	1182.9	0.2378	4.205	105
110	334.56	305.2	878.8	1184.0	0.2484	4.026	110
115	337.86	308.7	876.3	1185.0	0.2589	3.962	115
120	341.05	312.0	874.0	1186.0	0.2695	3.711	120
125	344.13	315.2	871.7	1186.9	0.2800	3.571	125
130	347.12	318.4	869.4	1187.8	0.2904	3.444	130
140	352.85	324.4	865.1	1189.5	0.3113	3.212	140
150	358.26	330.0	861.2	1191.2	0.3321	3.011	150

CHAPTER VII.

THE EXPANSIVE WORKING OF STEAM.

If we inclose a volume of gas in a cylinder having a movable piston and gage the pressure when the gas occupies the full volume, and if we then compress the gas to half that volume by moving the piston along the cylinder, the pressure will be found to have increased to double the original amount. By still further decreasing the volume to one third and then to one fourth of the original amount the pressure will be found to have increased correspondingly, whence we have Boyle's Law:

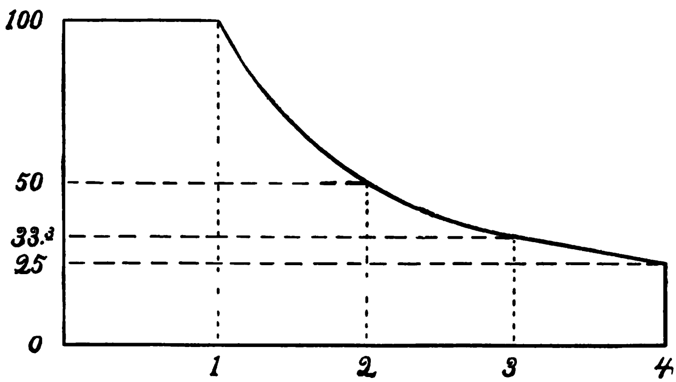


Fig. 24.

The volume of a gas varies inversely as the pressure, the temperature remaining constant.

Construct a diagram, Fig. 24, drawing first a hori-

zontal then a perpendicular line meeting at some point O (the perpendicular line representing the pressure, and the horizontal one the distances). Divide the horizontal line into four parts, and mark at some suitable point on the vertical line the number 100 to represent 100 pounds. Draw a vertical line from the number 1, on the horizontal line to an equal height with the 100 mark. Joining the two we will have a rectangle, representing a volume of gas at that pressure. Increase the volume to twice its size and the pressure will drop to one half or 50 pounds, and a horizontal line from that mark will meet a vertical line erected at the figure 2 on the line of distance, producing another rectangle. Repeating the same process with the distances 3 and 4, we have the resulting pressures 33.3 and 25 pounds respectively. These rectangles represent areas, and the product of the pressures and volumes indicated on their respective lines always produces a constant number, 100 in this instance. If the corners of the parts are connected, a curved line is produced which is the well-known hyperbolic curve. This theoretical isothermal curve is the true curve, showing the expansion of gases when maintained at a constant temperature.

It is not, however, a true curve for steam engines, as we are unable, for various reasons, to maintain the constant temperature in the steam engine cylinder.

As another illustration, given a volume of steam at a pressure of 100 pounds, expand it to six times its original volume, and the curve of expansion will be as shown in Fig. 25.

We have previously noted that the pound of water

converted into steam at a pressure of 100 pounds per square inch is capable of producing work equal to 62,352

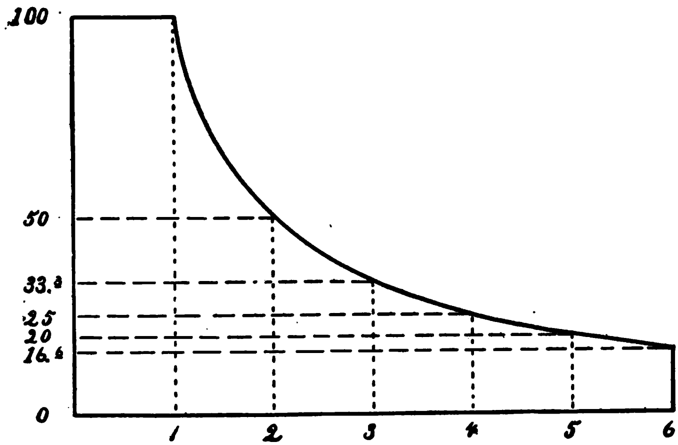


Fig. 25.

foot pounds; and under the same conditions, but at a pressure of 50 pounds per square inch, 59,832 foot pounds of work are produced, leaving a difference in favor of the higher pressure of 12,520 foot pounds.

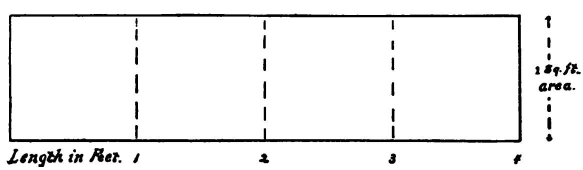


Fig. 26.

Now, by employing a cylinder represented by the diagram, Fig. 26, 1 pound of water converted into steam at a pressure of 50 pounds per square inch occupies a

volume of slightly over 8 cubic feet. It will, therefore, fill our cylinder, whose volume equals 4 cubic feet, twice.

If we allow the steam to enter from behind the piston, forcing it forward, and the steam continues to enter during the forward movement until, at the end of the stroke, the cylinder is filled with steam at a pressure of 50 pounds per square inch, the average pressure throughout the stroke will be 50 pounds per square inch, and the total work will be as follows:

$$
\begin{array}{rl}
144 & \text{sq. in.} \\
50 & \text{lb. per sq. in.} \\ \hline
7200 & \text{lb. total pressure} \\
4 & \text{ft. length of stroke} \\ \hline
28{,}800 & \text{ft. lb. per stroke} \\
2 & \text{strokes} \\ \hline
57{,}600 & \text{ft. lb. total work done.}
\end{array}
$$

If we transform the water into steam at a pressure of 100 pounds per square inch, while it has twice the pressure, the volume will be sufficient to fill the cylinder only once. As before, we have:

$$
\begin{array}{rl}
144 & \text{sq. in.} \\
100 & \text{lb. per sq. in.} \\ \hline
14{,}400 & \text{lb. total pressure} \\
4 & \text{ft.} \\ \hline
57{,}600 & \text{ft. lb. total work done.}
\end{array}
$$

In either case, the same amount of work has been done, but in the one instance the work was done during one stroke, while in the other it required two. Also, as we have previously seen, a slightly greater amount of coal was required to produce the higher steam pressure. So far, the results are equal.

Let us, however, use our steam at 100 pounds pressure, but, when the piston has gone one fourth of the stroke, close the steam valve, allowing no more steam to enter during that stroke.

THE POINT AT WHICH THE STEAM VALVE WAS CLOSED IS CALLED THE POINT OF CUT-OFF.

We now have in the cylinder one cubic foot of steam at a pressure of 100 pounds per square inch. The steam now expands until it occupies the entire volume of the cylinder and has forced the piston to the extreme end of its stroke.

According to the previous illustration, Fig. 24, the drop in pressure shown by the dotted lines will vary according to the following table:

Pressure at:

Beginning of stroke,			100 lb.;	end of	1st	quarter,	100 lb.
"	2nd	quarter,	100 lb.;	"	2nd	"	50 lb.
"	3rd	"	50 lb.;	"	3rd	"	33.3 lb.
"	4th	"	33.3 lb.;	"	4th	"	25 lb.

Average for	1st	quarter,	100 lb.
	2nd	"	75 lb.
	3rd	"	41.66 lb.
	4th	"	29.16 lb.
		4)	245.82
			61.45 lb.

= mean effective pressure (M.E.P.)

The average pressure, therefore, is 61.45 pounds; and we find at the end of this stroke steam of only 25 pounds pressure.

If we allow this to escape to the atmosphere it will be far less of a loss than when using it at full stroke under

a pressure of 100 pounds. Again the average pressure throughout the stroke was 61.45 pounds times 144 square inches times 4 feet which equals 35,395.2 foot pounds. This is more work than was done during one stroke when the low-pressure steam was used, and as we cut off the steam when only one fourth of it had entered the cylinder, we still have left 3 cubic feet of steam to use during other strokes; so that with this method, the total work done by the steam at 100 pounds pressure, cut-off at one-fourth stroke, equals 35,395.2 foot pounds times 4 strokes, or 141,580.8 foot pounds. This is 83,980.8 foot pounds of work more than could be done with the steam at 50 pounds pressure, at full stroke.

This gives us 2.45 times the power and requires only an additional amount of heat of 14 H.U.

Example. — Find the weight of steam or water used per hour, per H.P., at 100 lb. pressure, cut-off at one-fourth stroke, neglecting all loss.

Solution. — 61.45 lb. M.E.P.

$$\begin{array}{rl}
61.45 & \text{lb. M.E.P.} \\
144 & \text{sq. in.} \\
\hline
24580 & \\
24580 & \\
6145 & \\
\hline
8848.80 & \text{lb. total pressure.} \\
4 & \text{ft. stroke.} \\
\hline
35395.20 & \text{ft. lb. work during one stroke.} \\
4 & \text{strokes} \\
\hline
141{,}580.8 & \text{ft. lb. total work at 100 lb. pressure, at } \tfrac{1}{4} \text{ cut-off.}
\end{array}$$

Then with the given conditions we have,

$$\frac{\text{Work per H.P. per hour}}{\text{Work per lb. steam}} = \frac{1{,}980{,}000}{141{,}580.8} = 13.9 \text{ lb. of water.} \qquad \text{(Ans.)}$$

QUESTIONS.

1. Describe in detail the process of converting water into steam at atmospheric pressure.
2. What is saturated steam?
3. What is sensible heat?
4. What is latent heat?
5. What is a heat unit?
6. What is the mechanical equivalent of a heat unit?
7. What is the total heat of evaporation for steam at atmospheric pressure at 50 lb.; at 100 lb. absolute?
8. Give some advantage to be obtained by the use of high-pressure steam.
9. How much work is done in raising a piston 18 in. in diameter, 5 ft. against atmospheric pressure?
10. How is the efficiency of an engine determined?
11. How many pounds of water per hour are required for an engine producing 10 H.P., and using a pressure of 50 lb. per sq. in. at full stroke?
12. In the previous question what would be the result if the cut-off were at half stroke?
13. If the volume of steam at 90 lb. pressure is 4.79 cu. ft., find the external work done during formation.
14. Given a 16″ × 18″ engine, find the area of the piston and volume displaced per stroke, neglecting clearance.
15. If in the above question the pressure be 75 lb. per sq. in., the piston rod 3 in. in diameter, what will be the total pressure on each side of the piston?
16. What is Boyle's Law?
17. Draw a diagram showing the expansion of steam during the stroke, at ¼ cut-off, initial pressure being 75 lb.

CHAPTER VIII.

THE INDICATOR.

It is essential for the correct and economical operation of steam engines that we should know exactly what is taking place inside the cylinder. The diameter of the piston, length of the stroke, number of revolutions, and pressure of steam in the boiler are factors readily ascertained; but the pressure condition during the stroke, correct or incorrect operation of valves, loss from various causes, and other factors of importance must be ascertained while the engine is running. Even in a slow-speed engine the time required for one stroke is but a fractional part of a second, so the instrument employed for this purpose must be capable not only of indicating just what takes place in the cylinder during the stroke but of recording it in a permanent manner for future reference. Such an instrument is called an INDICATOR and the principle of its action is as follows: Suppose that to one end of the engine cylinder there were connected another small cylinder A, Fig. 27, about $\frac{5}{8}$ of an inch in diameter. It is evident that for any variation of pressure in the end of the engine cylinder there will be a like variation in the cylinder A, connected with it. If a piston B is placed in cylinder A the steam will act on it as it does on the engine piston C, but as the small piston is very light its movement must be opposed by such a resistance as will cause it to move in a manner similar

to the main piston. The piston-rod D passes through the cap E, which serves as a guide and holds the spring F. These springs are of steel and are stamped with numbers which represent the pounds per square inch which, when pressing on the piston, will move it against

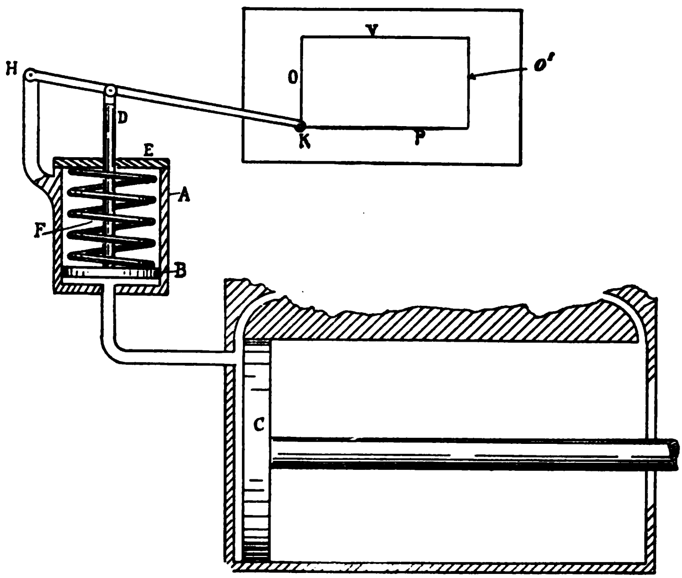


Fig. 27.

the pressure of the spring sufficiently to produce a diagram 1 inch high. The upward movement of the piston and rod, for instance in a pressure of 100 pounds per square inch, will, by means of the rod pivoted at H, raise the pencil K to a distance of 1 inch, O. Any weakening of the pressure will produce a corresponding lowering of the pencil, due to the spring acting on the

opposite side of the piston. If constructed as shown, the line drawn by the pencil would be curved; however, the addition of certain levers in the actual instrument enables us to produce a perfectly straight line. If, then, the pencil is allowed to rest on a sheet of paper, when the engine piston is at the beginning of the stroke, and if steam is admitted to the cylinder, the pencil instantly rises, drawing a line whose height represents the INITIAL PRESSURE or the pressure at the beginning of this stroke. If, while the piston C is moving forward, steam continues to be admitted, constant pressure maintained and the paper moved along at a rate proportional to the speed of the piston C, the horizontal line V will be drawn. Upon reaching the end of the stroke, the exhaust valve opens and, the pressure being released, the pencil drops along line O′ to its original level, completing the record of the stroke by drawing the line P during the return of the piston to its original position.

The height of the line O′ indicates the TERMINAL PRESSURE or pressure at the end of the stroke, while V, being of constant height, indicates that full pressure was carried throughout the stroke. In this case the average pressure was equal to the initial pressure. The area of the diagram is also indicative of the amount of work done. Thus we produce the diagram of what occurs on one side of the piston; for a diagram of the other side another indicator must be used. Or one instrument may be connected to both ends of the cylinder by a three-way valve which allows the record of either end to be made at will or entirely shuts off the instrument.

An illustration of a theoretical diagram from a non-condensing engine is given in Fig. 28. Before making the diagram and while the indicator cylinder is shut off from the engine, thus being subjected to atmospheric pressure only, the line A is produced. The admission of steam at the beginning of the stroke produces the admission line IS. From S to V the steam continues to be admitted; at V, which is the point of cut-off, the

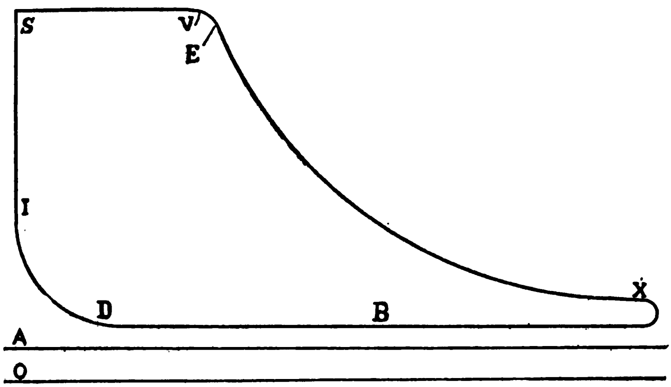


Fig. 28.

inlet valve begins to close. While its action appears to the eye to be instantaneous, it requires an appreciable amount of the time occupied by the entire stroke. From V to E the valve closes; from E to X is the expansion curve. At X the exhaust valve opens and the line B, by its height above zero, represents the absolute back pressure. At D the exhaust closes and the small amount of steam remaining in the cylinder is compressed during the remainder of the stroke, producing compression of steam at the end of the stroke and serving to cushion

the piston, and by slightly adding heat to the cylinder at this point the condensation of the incoming steam is reduced. In a non-condensing engine the back pressure is equal to the atmospheric pressure plus the resistance to the passage of the exhaust steam due to friction in the pipes, valves, fittings, etc. If, for example, we have an initial pressure in the cylinder of 100 pounds absolute,

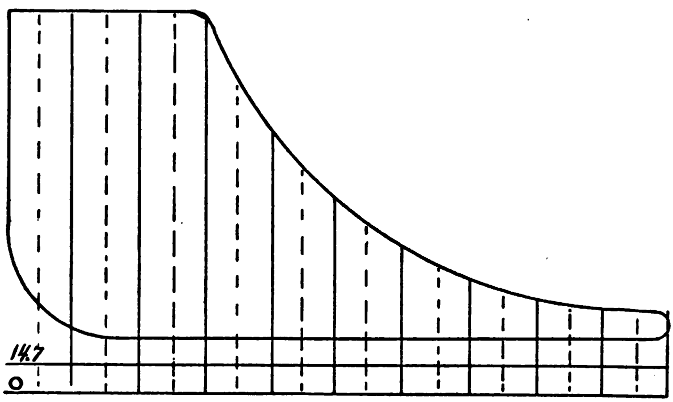


Fig. 29.

and the back pressure is 20 pounds absolute, we will have as effective pressure only 80 pounds, as we must use 20 pounds of the initial pressure to balance the 20 pounds back pressure. Now, as one of the reasons for making this diagram is to enable us to calculate the horse power of the engine, and as the effective pressure which does work varies during the stroke and according to conditions existing when the diagram is taken, it is therefore necessary to determine the average or mean effective pressure (M.E.P.) during the stroke. This is

found by subtracting the average back pressure from the average absolute pressure. The best method of doing this is by the use of the planimeter, described in another section. Where a planimeter is not available the following method is often used.

Divide the diagram vertically into a number of equal parts, usually ten, Fig. 29. Add the lengths of the dotted lines in inches in the center of each section and divide

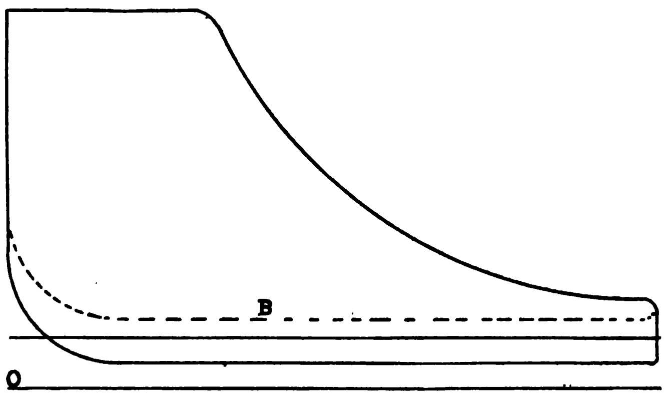


Fig. 30.

the sum by the number of sections. This result multiplied by the scale of the spring used equals the average pressure. Perform the same operation and measure up to the back-pressure line; the resulting average back pressure subtracted from the first result gives the mean effective pressure.

In a condensing engine the exhaust steam passes to a vessel where it is rapidly cooled and condensed to the form of water and the immediate result is a partial vacuum. On that side of the piston the back pressure

is reduced and the effective pressure correspondingly increased.

The resulting diagram is shown in Fig. 30, where the area below the original back-pressure line B is clear gain. In order to obtain the best results, however, from this method, it is advisable to apply it to compound engines.

INDICATOR CARDS.

A few points recorded by the indicator are shown in Figs. 31, 32, and 33.

The general outline of the diagram is shown by the dotted line; the solid line indicates the point of interest in each.

No. 1. — Too early admission. The full pressure is reached before the end of the stroke.

No. 2. — Late admission. The piston has begun to move forward and, the inlet valve not being open, the pressure, due to compression, drops, as shown by the little spire or point, until, steam being admitted, the pressure rises, but not with sufficient rapidity, on account of the forward movement of the piston, to produce a vertical line.

No. 3. — Early cut-off. The steam valve closes so early in the stroke that by the time the piston has reached two thirds of the stroke the smaller quantity of steam admitted has been expanded down to atmospheric pressure. From this point to the end of the stroke, the increased volume, causing decreased pressure, produces a partial vacuum in the cylinder, as shown by the loop below the atmospheric line. The area of this loop represents negative work.

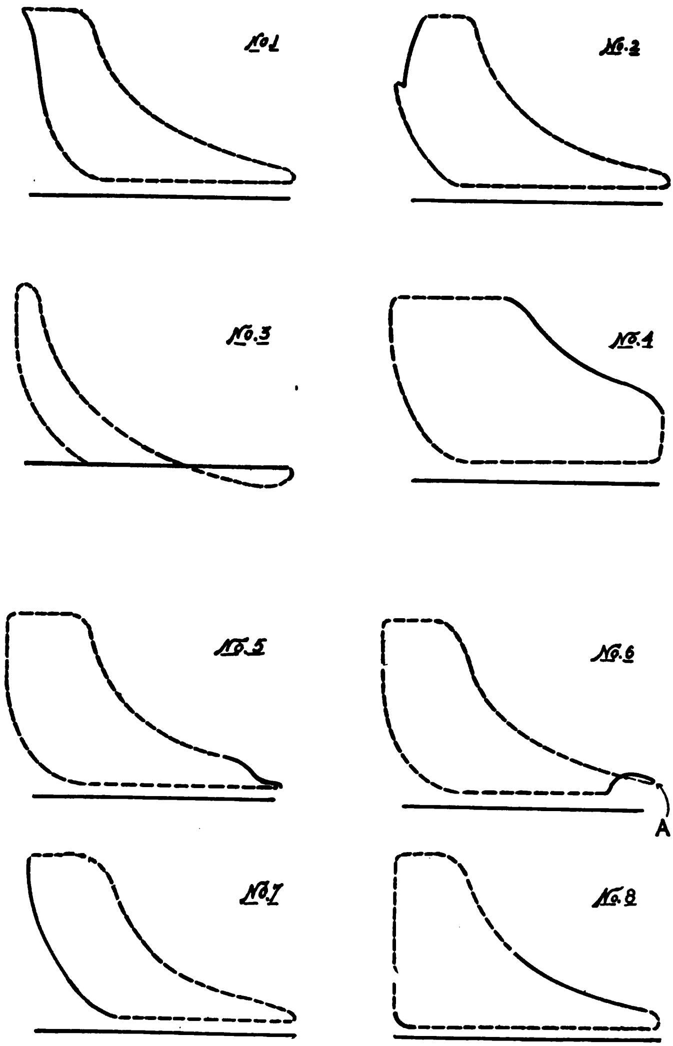


Fig. 31.

No. 4. — Showing engine running with a heavy load, point of cut-off occurring very late and the exhaust of steam at fairly high pressure.

No. 5. — In this case the exhaust valve opens and the steam passes out before reaching the end of the stroke, thus having no effect in propelling the engine during the last portion of the stroke.

No. 6. — The exhaust valve had not opened when the end of the stroke was reached and did not open until some little distance along the return stroke, as shown by the rise in back-pressure line, until a point was reached when the valve opened.

No. 7. — Exhaust valve closes early. As a result the compression is carried to a point greater even than the incoming steam pressure, as shown by the loop in the upper left-hand corner.

No. 8. — The opposite of the previous example. The valve closing too late produced very little compression.

No. 9. — Admission of steam took place at the proper time but either the throttle was not sufficiently opened or the supply pipes were too small because the pressure of steam was not maintained until the point of cut-off was reached, as shown by the gradual dropping of the line as the piston advanced. This is an illustration of wire drawing.

No. 10. — While the exhaust valve opened at the proper moment, there was not sufficient space for the rapid passage of the exhaust steam. As the piston returned upon its stroke the back-pressure line shows above its normal position, gradually reaching the correct point as the steam escaped, but requiring almost an entire stroke to produce this result.

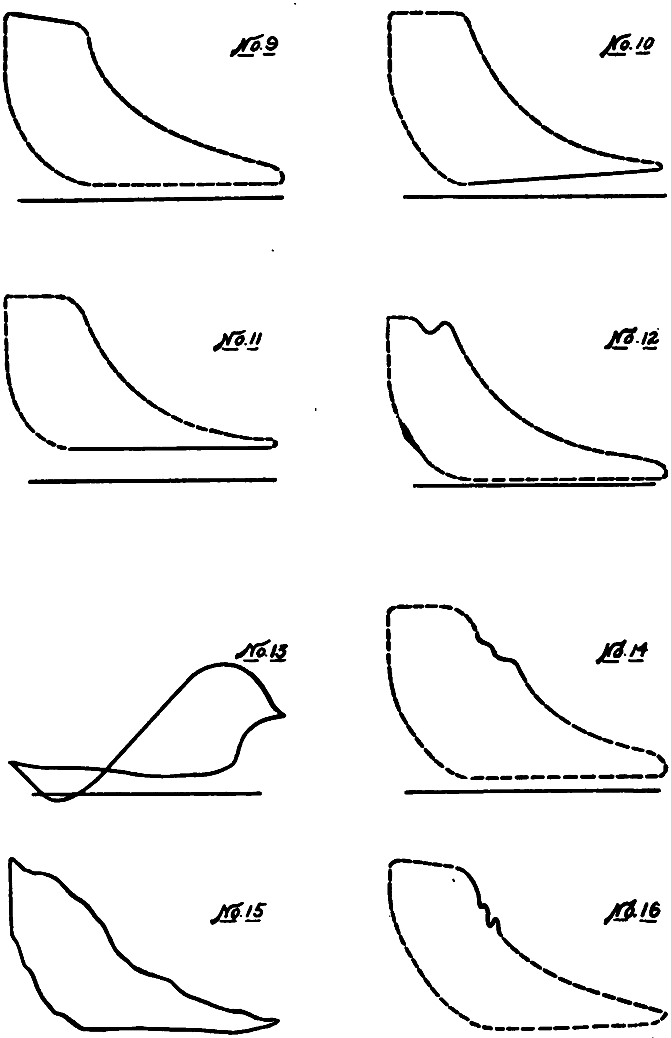


Fig. 32.

No. 11. — Shows a high back pressure due probably to some obstruction along the exhaust line.

No. 12. — Peculiar card taken from a Corliss engine where, at the point of cut-off, the dash-pot piston rebounded and opened the valve for an instant, letting in steam a second time.

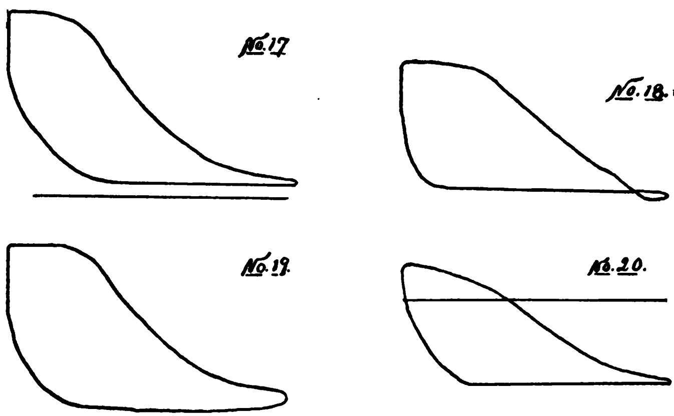


Fig. 33.

No. 13. — The eccentric had reduced angular advance so that the valve movement, taking place at incorrect periods, produced the peculiarly distorted card shown.

No. 14. — Cut-off occurred at the proper moment, but the leaky valve permitted some steam to enter, during the period of expansion, as shown by the wavy line.

No. 15. — Card taken from a high-speed engine, the wavy line being caused by the inertia of the indicator parts.

No. 16. — The peculiar lines shown were caused by the indicator piston being stuck.

No. 17. — Taken from the high-pressure cylinder of a Harrisburg ideal compound single-valve engine.

No. 18. — Taken from the low-pressure cylinder of the same engine.

Nos. 19–20. — Taken from a compound engine of the same make, but having four valves.

Knowing the area of the piston in square inches, the speed in feet per minute, and the mean effective pressure per square inch in pounds, the quotient of their continued product divided by 33,000 will give the indicated horse power (I.H.P.).

Where a number of diagrams from the same engine is to be figured, the work may be simplified by multiplying the area of the piston by twice the stroke and dividing the product by 33,000. We now have the "*engine constant*," or the power that would be developed at one revolution per minute at one pound M.E.P.

The revolutions per minute multiplied by the mean effective pressure times this constant equals the I.H.P.

Should the engine run at an even speed during the test, then the engine constant times the revolutions gives us the "*horse-power constant*" or H.P. per pound of M.E.P.; and the indicated horse power may be found by multiplying the engine constant by the mean effective pressure.

QUESTIONS.

1. What is meant by the "point of cut-off"?
2. With 100 lb. initial pressure, $\frac{1}{4}$ cut-off, and back pressure, what will be the mean effective pressure on the piston?
3. Given 100 lb. initial pressure, $\frac{1}{3}$ cut-off, what will be the average pressure throughout the stroke, back pressure being neglected?
4. In the above question, if the stroke is 4 ft., give the pressure at each foot of the stroke.
5. Draw a diagram illustrating the above.

CHAPTER IX.

DESCRIPTION OF INDICATOR.

The previous description of the principles of an indicator gives a faint idea of the actual construction of the instrument. A more definite idea may be gained by referring to Fig. 34. In this case the indicator as a whole is shown ready to be attached to the pipes connecting to the cylinder by means of the union.

Part 4 is the cylinder proper, in which the movements of the piston take place. It is made of a special alloy, exactly suited to the varying temperature to which it is subjected, and secures to the piston the same freedom of movement with high-pressure steam as with low. As its bottom end is free and out of contact with all other parts, its longitudinal expansion or contraction is unimpeded and no distortion can possibly take place.

Between the parts 4 and 5 is an annular chamber, which serves as a steam jacket. This being open at the bottom, it can hold no water, but will always be filled with steam of nearly the same temperature as that in the cylinder.

The piston, 8, is formed from a solid piece of the finest tool steel. Its shell is made as thin as possible consistent with proper strength. It is hardened to prevent any reduction of its area by wearing, then ground and lapped to fit (to the ten-thousandth part of an inch) a cylindrical gage of standard size. Shallow channels in

its outer surface provide a steam packing, and the moisture and oil which they retain act as lubricants and prevent undue leakage past the piston. The transverse

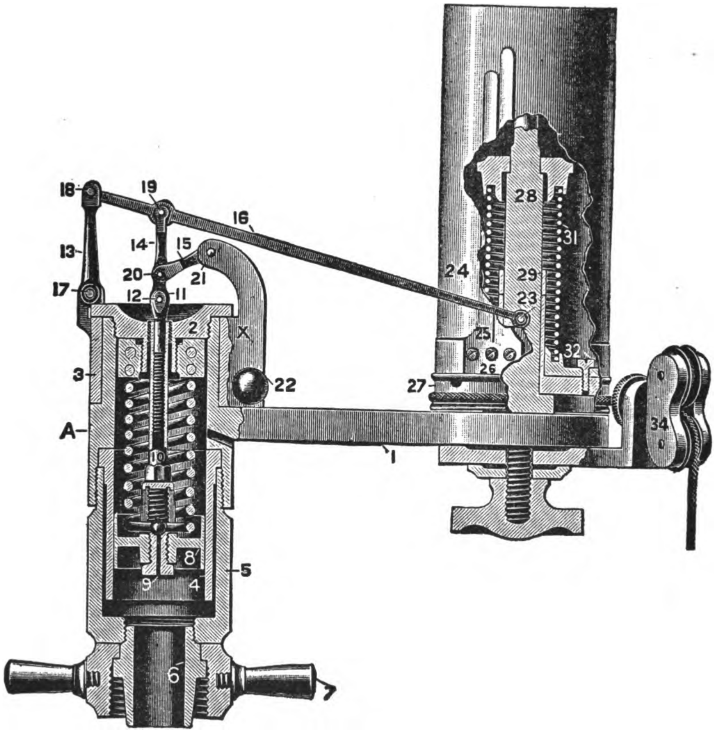


Fig. 34.

web, near its center, supports a central socket which projects both upward and downward; the upper part is threaded inside to receive the lower end of the piston-rod; the upper edge of this socket is formed to fit nicely into a circular channel in the under side of the shoulder

of the piston-rod. It has a longitudinal slot which permits the straight portion of wire at the bottom of the spring, with its bead, to drop to a concave bearing in the upper end of the piston-screw, 9, which is closely threaded into the lower part of the socket. The head of this screw is hexagonal and may be turned with a hollow wrench.

The piston-rod, 10, is of steel and is made hollow for lightness. Its lower end is threaded to screw into the upper socket of the piston. Above the threaded portion is a shoulder having in its under side a circular channel formed to receive the upper edge of the socket when these parts are connected together. When this connection is made the piston-rod is screwed into the socket as far as it will go; that is, until the upper edge of the socket is brought firmly against the bottom of the channel in the piston-rod. This is very important, as it insures a correct alignment of the parts, and a free movement of the piston within the cylinder.

The swivel head, 11, is threaded on its lower half to screw into the piston-rod more or less, according to the required height of the atmospheric line on the diagram. Its head is pivoted to the piston-rod link of the pencil mechanism.

The cap, 2, rests on top of the cylinder and holds the sleeve and all connected parts in place. It has a central depression in its upper surface, also a central hole, furnished with a hardened steel bushing, which serves as a very durable and sure guide to the piston-rod. It projects downward into the cylinder in two steps, having different lengths and diameters; both these and the

hole have a common center. The lower and smaller projection is screw-threaded outside to engage with the like threads in the head of the spring and holds it firmly in place. The upper and larger projection is screw-threaded on its lower half to engage with the light threads inside the cylinder; the upper half of this larger projection — being the smooth vertical portion — is accurately fitted into a corresponding recess in the top of the cylinder, and forms thereby a guide by which all the moving parts are adjusted and kept in correct alignment, which is very important, but which is impossible to secure by the use of screw threads alone.

The sleeve, 3, surrounds the upper part of the cylinder in a recess formed for that purpose, and supports the pencil mechanism; the arm, X, is an integral part of it. It turns around freely, and is held in place by the cap. The handle for adjusting the pencil point is threaded through the arm, and is in contact with a stop-screw in the plate, I. This may be delicately adjusted to the surface of the paper drum. It is made of hard wood in two sections; the inner one may be used as a lock-nut to maintain the adjustment.

The pencil mechanism is designed to afford sufficient strength and steadiness of movement, with the utmost lightness; thereby eliminating, as far as possible, the effect of momentum, which is especially troublesome in high-speed work. Its fundamental kinematic principle is that of the pantograph. The fulcrum of the mechanism as a whole, the point attached to the piston-rod, and the pencil point are always in a straight line. This gives to the pencil point a movement exactly parallel with that

of the piston. The movement of the spring throughout its range bears a constant ratio to the force applied and the amount of this movement is multiplied six times at the pencil point. The pencil lever, links, and pins are all made of hardened steel; the latter — slightly tapering — are ground and lapped to fit accurately, without perceptible friction or lost motion.

The drum, 24, is for the purpose of holding the paper on which the diagram is made, and contains a volute spring, 31, for the purpose of returning the drum to its starting point when the pull on the cord is released.

The metallic faced paper employed is held in position by the two spring clips, 25, shown on the side of the drum.

As the movement of the drum is limited and a drawing or diagram cannot be made longer than about $\frac{3}{4}$ of its circumference, producing a card perhaps 4 or 5 inches long, it is evident that in using the instrument on an engine having a longer stroke than this, some means must be taken for reducing the motion between the indicator and the point where the cord operating the drum is fastened to the engine. For this purpose various methods are employed. The most convenient is that of the reducing wheel shown attached to the indicator, Fig. 35.

This apparatus consists of a wheel A of variable diameter, to which the cord, leading from the indicator drum, is fastened.

The wheel itself carries a large beveled gear and is operated through a smaller beveled gear on the spindle of wheel B.

The horizontal cylinder contains a spring, which is connected to the shaft of wheel A, and serves to take up any lost motion.

Wheel B is connected by a cord wound around it to

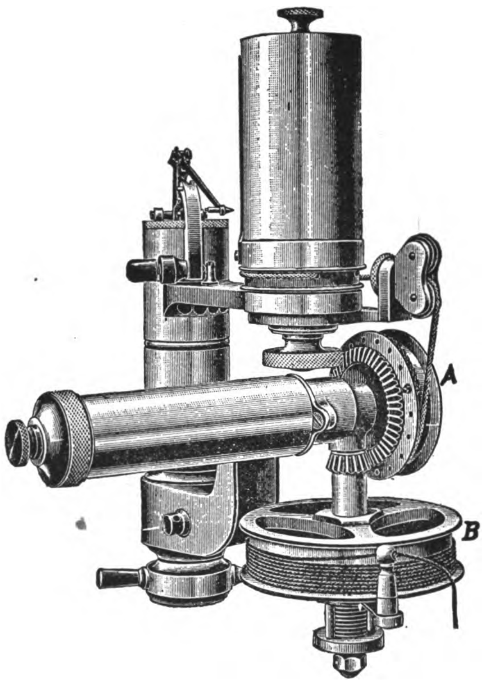


Fig. 35.

the cross-head of the engine. If then the circumference of wheel B equals eight inches and the stroke of the engine is 24 inches, each stroke will cause wheel B to revolve three times. If the small gear connected to wheel B is $\frac{1}{2}$ of an inch in diameter and the one con-

nected to wheel A is 2 inches in diameter, the 3 revolutions of wheel B will cause wheel A to make $\frac{3}{4}$ of a revolution. If the circumference of wheel A, then, is

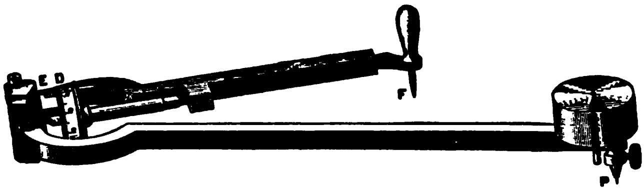


Fig. 36.

6 inches, $\frac{3}{4}$ of its revolution will equal $4\frac{1}{2}$ inches, which is the amount that the paper drum connected to it will be caused to move under the pencil; a diagram of that length will be the result.

In Fig. 36 is shown a form of planimeter, an instrument designed to facilitate the measurement of the areas of plane figures of irregular outline. The figures on the roller wheel represent square inches, the graduations in the wheel, tenths, and the vernier E, hundredths.

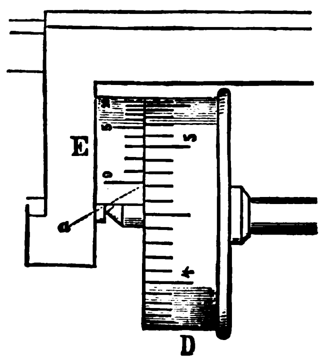


Fig. 37.

Fig. 37 shows in detail the recording mechanism of a planimeter from which the method of reading may be easily understood. D is the roller wheel and E the vernier. From the roller wheel we read 4 (units) for

the last figure that has passed zero on the vernier; we also read 7 (tenths) for that number of graduations beyond 4 that have also passed zero on the vernier (shown by the dotted line *a*). Then from the vernier we read 3 (hundredths) because the third graduation on the vernier coincides with a graduation on the roller wheel.

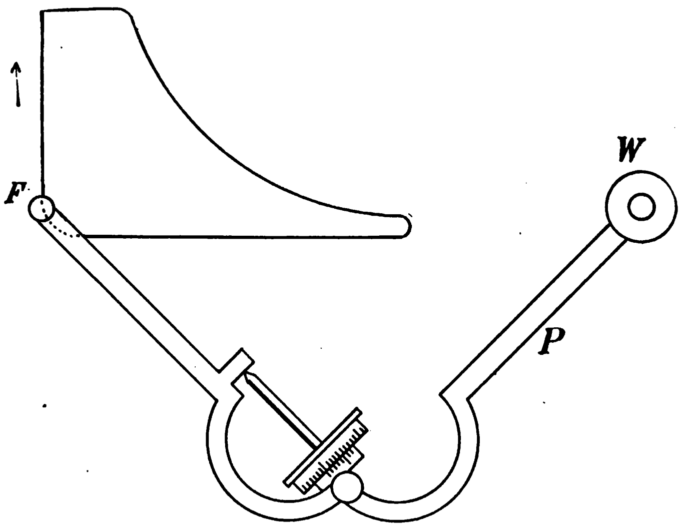


Fig. 38.

The complete reading will then be 14.73 square inches.

Care should be taken to have a flat, even, unglazed surface for the roller wheel to travel upon. A sheet of dull finished cardboard serves the purpose very well.

Set the weight W in position on the pivot end of the bar P, and after placing the instrument and the diagram in about the position shown in Fig. 38, press down the needle point under the weight so that it will hold its

place; set the tracer point at any given point in the outline of the diagram, as at F, and adjust the roller wheel to zero. Now follow the outline of the diagram carefully with the tracer point, moving it in the direction indicated by the arrow, or that of the hands of a watch, until it returns to the point of beginning. The result may then be read as follows: Suppose we find that the largest figure on the roller wheel D, Fig. 37, that has passed zero on the vernier E, is 2 (units), and the number of graduations that have also passed zero on the vernier is 4 (tenths), and the number of the graduation on the vernier which exactly coincides with a graduation on the wheel is 8 (hundredths). Then we have 2.48 square inches as the area of the diagram. Divide this by the length of the diagram, which we will call 3 inches, and we have 0.8266 inch as the average height of the diagram. Multiply this by the scale of the spring used in taking the diagram, which in this case is 40, and we have 33.06 pounds as the mean effective pressure per square inch on the piston of the engine.

After taking a diagram it is advisable to compare it, particularly the expansion line, with a theoretical one, in order to see how closely the operation of the engine approximates ideal conditions.

In order to do this conveniently it is necessary to find the clearance line, which is done as follows:

Placing the card, preferably on the drawing board (but any smooth surface will serve), and using the proper scale, we draw the vacuum or zero line *o* at a distance representing 14.7 pounds below the atmospheric line *g*, Fig. 39 (the distance will depend on the spring used).

Then draw the line *ab* cutting the compression curve at two points *c* and *d* as shown. Take the distance *ec* and, with the point *d* as a center, mark a distance equal to *ec* on the line *da*, producing the point *f*. Next erect a perpendicular passing through this point and connecting with the zero line; this is the clearance line.

To draw the theoretical expansion curve, let us lay off

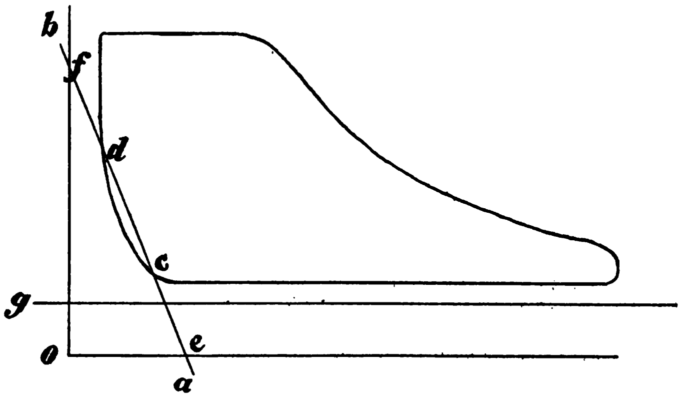


Fig. 39.

the horizontal line *ef*, Fig. 40, at a height equal to the boiler pressure, measured by the scale, the record having been taken at the boiler and noted on the back of the card at the time of taking it. From some point on the expansion line just before the place where the exhaust valve opens, draw a perpendicular reaching the line *ef* at the point *w*, and from this point draw the diagonal *wo* to the intersection of the clearance and zero lines. Now draw a horizontal line from *x* cutting the line *wo*, at *d*, and from this point erect a perpendicular *dc*, and the point *c* will be the theoretical point of cut-off.

To get the other points of the curve, lay out any convenient number of points on pressure line *ef* and from these draw diagonals to *o*. Drop perpendiculars from each of these points, and from the intersection of the diagonal lines with the line *cd* draw horizontals meeting the perpendiculars. Draw through these various points

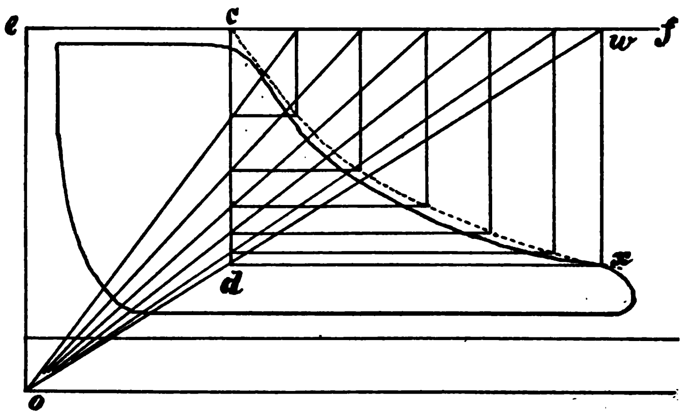


Fig. 40.

of intersection a line *cx* and a theoretical curve is produced.

As previously mentioned a certain amount of the power is required to operate the engine itself. This is called the friction horse power.

In order to determine the actual H.P. delivered to the shaft it is necessary to make a test when the engine is running alone, and when it is supplying the load.

Subtract the one from the other and the result will be the actual H.P. delivered to the shaft.

The mechanical efficiency of an engine is the ratio of

the actual H.P. to the indicated H.P. In other words it is the percentage of the energy developed which is utilized in doing useful work.

To find the efficiency of an engine, we divide the actual H.P. by the indicated H.P.

QUESTIONS.

1. Sketch and describe an indicator.
2. Explain its use.
3. Draw a theoretical diagram and name the parts.
4. What is initial pressure, terminal pressure, atmospheric pressure?
5. What is mean effective pressure?
6. What is an "engine constant" and its use?
7. What is a reducing wheel?
8. Describe the planimeter and its use.
9. How is the mean effective pressure (M.E.P.) found from the diagram?
10. How may the clearance line be found?
11. How may the expansion line of the diagram be compared with a theoretical one?
12. Make a diagram and find the mean effective pressure of an engine using steam at 150 lb. initial pressure, $\frac{1}{5}$ cut-off, back pressure one pound above atmospheric pressure.

CHAPTER X.

HEAT.

All power plants, whether on a large or small scale, if intended for the production of power by the transformation of water into steam and by means of engines converting latent energy into mechanical work, are very much alike as far as the essential principles are concerned.

The individual plant will differ as to size, method of construction, pressure developed, character and kind of accessories, according to the various conditions governing the installation and operation of each particular plant. Boilers, engines, pumps, piping for the transmission of steam and water, means for supplying and heating feed water, preventing the condensation of steam, and such other apparatus as may be necessary to produce the required results are common to all steam plants.

In such plants the production of heat and the resultant steam is the first thing to be considered. Heat is produced by the combustion of fuel. Different fuels produce different amounts of heat. Some of this heat is lost. The remainder changes the water to steam which, under pressure admitted to an engine, enables it to do mechanical work. This may be applied either directly to the operation of machinery or indirectly by means of a dynamo, to produce electric energy which,

by means of wires, may be conducted to and used at a distant point.

As, therefore, each step is the result of the previous one, it is clear that each depends upon the other and has some definite relation to it, and that the amount of coal burned and water used to produce power to operate a given motor, or electric lamp, may readily be calculated if the operating conditions are carefully studied and proper allowances made for the losses due to various causes in passing through the several stages from the burning of the fuel to the final use of the power. Such calculations naturally imply some definite base to begin with, and as we have in every-day use the inch, foot, and quart, mention of which produce definite images in our minds, so the engineer has a number of units of measurement with which to measure his work.

If heat is applied to a body the weight of the body will not change. If sufficient heat is applied to water it will change into steam but the weight will be as before. If the water is in a closed vessel the heat will cause it to expand and the force of this expansion, which increases as the continuation of the heat makes the steam hotter, produces a pressure on the sides of the vessel. This PRESSURE, which is measured in pounds per SQUARE INCH of surface, indicates the power of the steam to do work, but it is distinct from, and must not be confused with, the WEIGHT of the steam.

The temperature of a body indicates how hot or how cold a body is, or the intensity of its heat. This is different from the quantity of its heat. For example, if a pint of water is taken from a pail holding a gallon, the

temperature of both will be alike, but there will be a greater quantity of heat in the one than in the other.

Temperature is indicated by an instrument called the thermometer. This is a sealed glass tube containing a small amount of mercury or alcohol; the portion of the tube not so occupied has been exhausted of air. A change of temperature causes the liquid to rise or fall in the tube and the amount is read in degrees indicated by marks or graduations on the side of the tube.

The principal points are obtained by placing the instrument into vessels containing respectively melting ice and boiling water. The points where the liquids come to rest under these conditions are called the freezing point and the boiling point.

On the Fahrenheit thermometer the space between these points is divided into 180 degrees, the freezing point being marked 32° and the boiling point 212°. On the Centigrade and Reamur thermometers freezing is marked zero; the boiling point of the former 100° and the latter 80°.

Temperatures below zero are marked with the negative sign, thus -15 means fifteen degrees below zero.

As the two former instruments are largely used in this country it is often necessary to change from one to the other, so we have these rules.

To change Fahrenheit to Centigrade, subtract 32, multiply the remainder by 5 and divide by 9.

To change Centigrade to Fahrenheit, multiply degrees Centigrade by 9, divide by 5 and add 32.

As the amount of heat required to raise the temperature of water one degree varies according to con-

ditions, the heat unit is measured with pure water when at its greatest density, and we have:

The UNIT OF HEAT, or British Thermal Unit (B.T.U.), is that quantity of heat required to raise the temperature of 1 pound of pure water 1 degree Fahrenheit when at its greatest density or 39.1° F.

The SPECIFIC HEAT of a substance is the amount of heat required to raise the temperature of the substance 1 degree, compared to the amount of heat required to raise an equal weight of water 1 degree.

For accurate work a definite and uniform zero is required. This point is 461° below zero Fahrenheit, and must be added to the thermometer reading, when it is desired to express absolute temperature.

The UNIT OF WORK is called the FOOT POUND, and is equal to the amount of work done in raising a weight of 1 pound a distance of 1 foot. Thus, if a weight of 1 pound is to be raised 100 feet, or a weight of 50 pounds is to be raised 2 feet, the total amount of work in either case will be the same, or 100 foot pounds. This is found by multiplying the weight in pounds by the distance in feet through which it is raised. The result is foot pounds.

This, however, does not consider the time required to do the work and it is evident that if in one case the work is performed in a shorter time than in the other, then one is working at a higher *rate* than the other. For this reason and in order that the mechanical efficiency of various engines may be compared, their rating is based on their ability to do work at a given rate, or to deliver a certain number of foot pounds of work in the unit of time.

The UNIT OF TIME used by engineers is ONE MINUTE.

The UNIT OF POWER is the HORSE POWER.

The HORSE POWER is equal to 33,000 FOOT POUNDS of work done in one minute.

Therefore, if the work done in foot pounds is divided by 33,000 times the time in minutes, the result will be the horse power exerted.

As already mentioned heat units may be changed into work units. There must then be some definite relation between them. Careful investigation has shown that 778 FOOT POUNDS IS THE MECHANICAL EQUIVALENT OF A HEAT UNIT. In other words, if the heat of the fuel were to pass through the various processes to the final change into mechanical work without loss, each unit of heat would produce 778 foot pounds of work.

Experiment has shown that a good quality of coal is capable of producing 14,000 heat units per pound of fuel. Now as 14,000 times 778 equals 10,892,000, then a pound of good coal, if it could be completely burned and used to produce power, with absolutely no waste, would do 10,892,000 foot pounds of work. Or, as one horse power per hour equals 33,000 foot pounds $\times$ 60 minutes = 1,980,000 foot pounds, we have $\frac{10{,}892{,}000}{1{,}980{,}000} = 5.5$ H.P., or the amount of energy one pound of fuel would develop per minute under these conditions.

Of course this can never occur in practice, as a large amount of its energy is lost, due to radiation, condensation and other causes to be mentioned later.

The transfer of heat from one body to another takes place in several ways.

By RADIATION. From the sun, from a fire, or from similar sources, the heat is given off in straight lines or rays.

By CONDUCTION. The heat from the fire striking one side of the boiler plates is conducted from one particle of steel to another until, reaching the side in contact with the water, it heats the water. If you hold one end of a piece of metal with its opposite end in the fire, the end you hold will shortly become hot also. Such bodies which conduct the heat readily are called good conductors. Bad conductors, as asbestos, felt, etc., are used to cover steam pipes and other apparatus to prevent the condensation of the steam.

By CONVECTION. This is heat which is transmitted by currents. If a glass of water containing a little meal be placed on the stove and carefully watched you will see, as the water becomes hot, that the meal is being carried around in a current, the speed of which increases as the water gets hotter. The same thing occurs in a boiler. The drops of water at the bottom of the boiler become warm, on account of being in contact with the part of the boiler directly over the fire. These expand and their specific gravity thus becoming less, as compared to the other drops, they rise to the top, while colder, heavier drops take their place. This continues until the whole mass of water is in motion, thus forming the current, and as each drop in turn passes again over the heated part it gets hotter, until finally, once more reaching the surface, it bursts into a gas called steam. With pure water at the sea level this change takes place at a temperature of 212° F., if the water is heated in an

open vessel. If the vessel is closed the pressure on the surface will be increased. This is due to the compression of the air or steam above the water in the vessel, and the steam will not be formed until a higher temperature has been attained.

QUESTIONS.

1. What is the effect of heat on the weight of a body?
2. What does temperature indicate?
3. Describe a thermometer.
4. What is a unit of heat?
5. Define specific heat.
6. What is the unit of power?
7. What is the unit of work?
8. What period of time is employed when calculating the rate of doing work?
9. What is the mechanical equivalent of a heat unit?
10. How many heat units does a pound of good coal contain?
11. In what manner may the transfer of heat take place?
12. How many foot pounds of work would be produced by two pounds of good coal if they were completely consumed with no loss?
13. If the foot pounds of work in the answer to the previous question were delivered by an engine during one hour, at what rate would it be doing work?

CHAPTER XI.

BOILERS.

A boiler is a metallic vessel of suitable size and shape in which water is changed into steam by the application of heat. Boilers for pressure purposes are made of steel, of wrought iron, and occasionally of cast iron.

Boilers in use are exposed to strains due to the pressure of the contained steam and to strains due to the constant expansion and contraction due to changes in temperature. They are also likely to be weakened by careless handling as well as by corrosion due to the chemical action of substances in solution in the water used.

In selecting material for a boiler we should choose that grade of material best fitted to withstand these troubles. Boiler materials should have good tensile strength and high elastic limit. They should be tough, ductile, and homogeneous.

By TENSILE STRENGTH is meant the force or pull required to break a piece of material one square inch in cross section, the force being applied in the direction of its length.

Metals are to some extent elastic, so that a pull of a small amount will stretch a bar of metal slightly, and on being released it will return to its original form. By gradually increasing the amount of pull, a point will be reached where, after a slight elongation, the metal will not entirely resume its original form. This point is called its ELASTIC LIMIT.

By HOMOGENEOUS is meant that all parts of the metal are alike and of equal density and texture.

By TOUGH AND DUCTILE is meant that the metal may be readily formed into the required shape and will not readily break when exposed to repeated bending.

The following are a few definitions of terms employed in connection with the construction of boilers and engines.

ALLOY. — An alloy is a mixture of two or more metals.

TENSILE STRENGTH. — The force which, gradually applied in the direction of its length, will overcome the cohesion of the particles and produce fracture; usually stated as a certain number of pounds per square inch.

ELASTIC LIMIT. — The force which, applied in the direction of its length, will produce a permanent distortion of the material.

SHEARING STRENGTH. — The force which, applied at right angles to its axis, will shear or cut the material.

TORSIONAL STRENGTH. — The power of the material to resist a twisting strain.

STRESS. — The internal resistance of a body to a force tending to overcome the cohesion of its particles.

STRAIN.—The amount of deformation due to a stress.

ELONGATION. — The amount a body will stretch or lengthen before breaking.

COMPRESSION STRENGTH. — The ability of a body to withstand pressure or squeezing.

FACTOR OF SAFETY. — The ratio of the ultimate strength of a body to the actual stress which it is expected the body will be subjected.

MALLEABLE. — Capable of being hammered or rolled without breaking.

DUCTILE. — Capable of being bent without fracture.

HOMOGENEOUS. — Meaning that all parts are of even quality, grade, and fibre.

Unless otherwise mentioned the standard tensile strength of steel used in boiler construction is understood to be 60,000 pounds per square inch. Steel of much greater strength than this is made, but it is too brittle and therefore unsuited for boiler construction. Wrought iron is still largely used for boiler purposes, but the quality employed is of such high grade that it may perhaps be more properly called a grade of mild steel.

Cast iron is rarely employed in the construction of high-pressure boilers and then only in such forms and sizes as will enable it to develop the greatest strength.

The molecules of iron and steel hold together by cohesion. Any force which tends to separate the molecules is a stress. The amount that the metal is pulled apart or otherwise deformed is a strain.

If, therefore, we have a bar of metal 1 square inch in area, 12 inches long, exposed to a pull of 2000 pounds, and lengthened $\frac{1}{2}$ inch by the pull, then the pull is the stress and the $\frac{1}{2}$ inch is the strain. As the pull is exerted on 1 square inch, the 2000 pounds is, in this case, the unit stress or the intensity of the stress. The unit strain will be the elongation per unit of length (1 inch), or in this case $\frac{1}{2}$ inch divided by 12 inches or $\frac{1}{24}$ of one inch.

It would not be safe to subject the boiler to anything like a stress equal to the elastic limit of the material composing it, for fear of some unknown weak spot and

on account of the constant weakening and the deterioration due to use. For this reason the FACTOR OF SAFETY is employed. This is a number by which the tensile strength of the material is divided to obtain the safe working stress or pressure.

CHAPTER XII.

FIRE-TUBE BOILERS.

According to the method of heating the water, boilers may be divided into two general classes, as fire-tube and water-tube boilers; and according to construction, as horizontal, vertical, or inclined.

Fire-tube boilers are largely used for stationary, locomotive, and marine work. While they differ slightly on account of the conditions existing where they are employed, still a description of a horizontal stationary boiler will essentially be that of a fire-tube boiler wherever used.

The cylindrical portion of the boiler is called the shell. This is made of two or more sheets of metal fastened with rivets.

The ends of the boiler are called the heads and are thicker than the shell because, although the pressure per square inch due to the steam is the same on all parts of the boiler, the heads, being flat, are mechanically weaker. It is evident that such a vessel will contain a large amount of water and that the fire will heat only a small part of the lower surface; also that the rapidly moving heated gases will pass along and leave the boiler while they are yet very hot.

If, therefore, they are made to pass along the surface of the boiler again, less heat will be wasted and the water will be heated more quickly. The first step in this

direction is to cut a hole in each head and insert a pipe or tube; now, if by means of brickwork the heated gases, after passing along the bottom of the boiler, are made to pass through the tube before passing to the chimney or stack, an advantage will be gained due to the increased

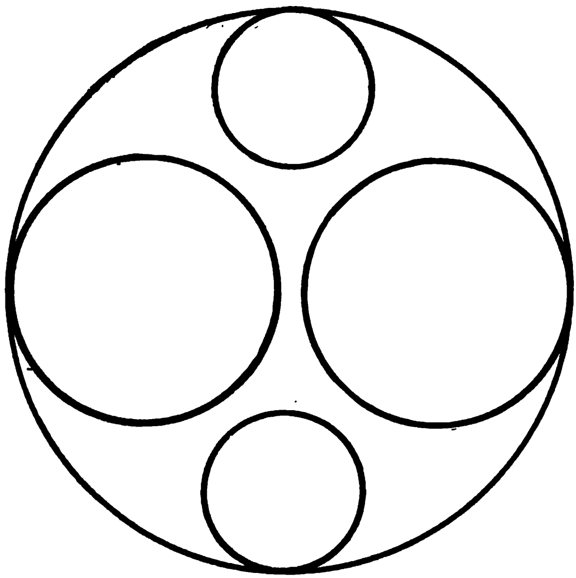


Fig. 41.

heating surface. That is, with the increased area of metal in contact with the heated gases on one side and the water on the other, there will be an increase of temperature with less waste.

If the boiler were 12 feet long and the tube 1 foot in diameter, the additional surface would be equal to 37.6 square feet. Now, suppose that, instead of this

tube, two tubes six inches in diameter are used, the heating surface will be the same and room will be left in the space occupied by the larger tube for the insertion of two smaller tubes, Fig. 41. Thus, in modern practice, a large number of small tubes two or three inches in diameter are used in stationary work, and many of smaller diameter in locomotive and marine boilers. By this method there is not only a gain of a great amount of heating surface, but as only the outer surface of the column of rapidly moving gas has time to impart its heat to the metal, during the short time in which it passes through the boiler, the many tubes separate the mass of heated gas into small portions, each of which gives up a part of its heat, and so a much smaller part of the total heat generated passes into the stack and is lost.

When the tubes, Fig. 42, are in position the ends project slightly beyond the flat surfaces of the heads. They are then expanded and rolled until they fit tightly in place. In this way they also serve to strengthen the flat heads. As the tubes do not fill the entire boiler the portion of the heads above the tubes must be supported. This is done by the braces *bbbb*. These are riveted to the shell and head and are so distributed and proportioned that each supports an equal amount of the flat surface.

When in use the water partially fills the space above the upper row of tubes, the remainder being the steam space. As the steam in contact with the surface of the water still retains a quantity of water, it is necessary, in order to take the steam out as dry as possible, to make the connection for this purpose as far as possible from

the surface of the water. To facilitate the production of dry steam, some boilers have a dome, A, Fig. 42. In

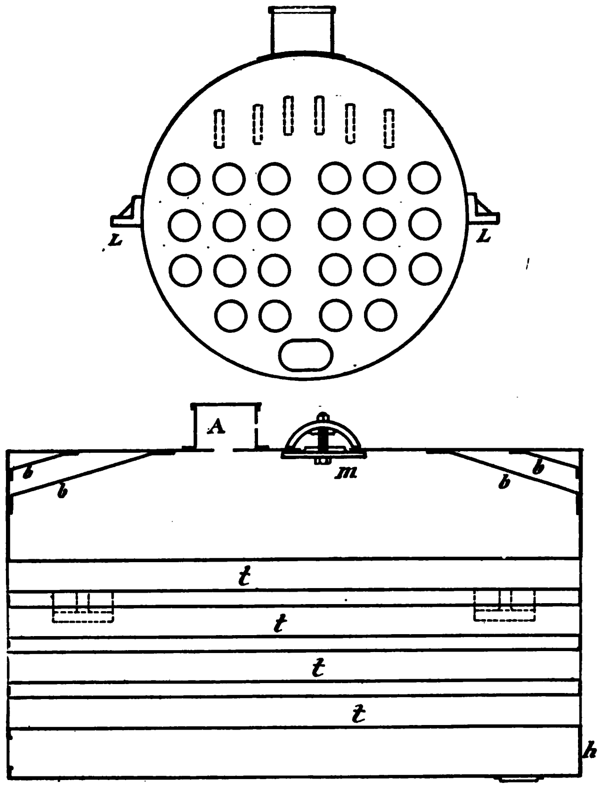


Fig. 42.

some cases the steam connection is made at the upper part of the dome; in others there is a short section of heavy pipe, called the dry pipe, so connected as to take its place. To provide access to the interior, an oval

opening *m*, called the manhole, about 10 inches by 14 inches, is cut in the upper part of the boiler shell. This is closed by a plate placed in the boiler and held against it by a bolt fastened to the plate and passing through a casting called a spider, all being drawn tightly together by a nut on the bolt. Where the surface of the plate and

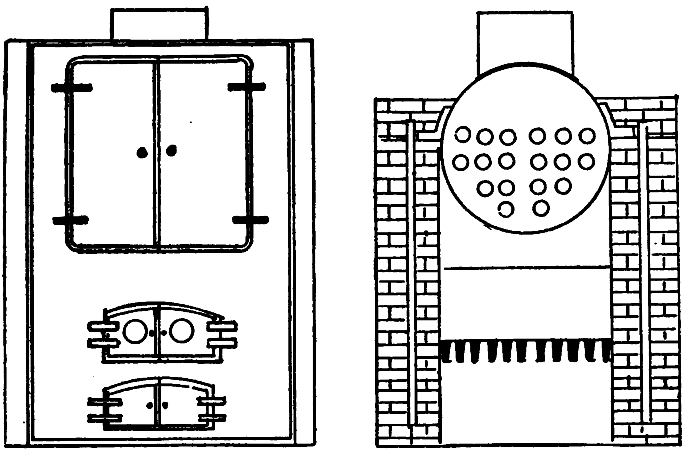


Fig. 43.

the edge of the opening touch, a gasket of sheet packing is placed in order to make the joint steam-tight.

At the bottom of the front and back heads, similar but smaller openings and plates, *h*, called handholes, are provided.

On each side of the boiler, lugs or brackets, *LL*, are placed. These are for the purpose of supporting it on the brickwork. Some boilers are hung on chains from a framework of iron.

Locomotive or marine boilers are self-contained; that

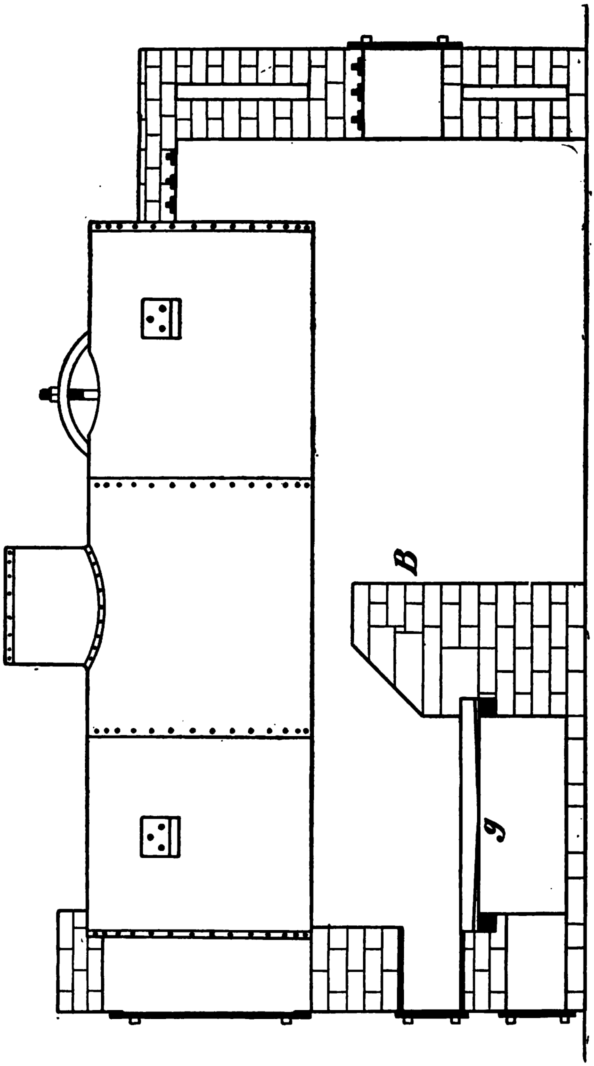


Fig. 44.

is, the fire box and grates are all part of and in the boiler itself; for stationary work, however, the fire box and grates are in the brickwork of the boiler setting. The side walls of this setting are built double, and as air at rest is a bad conductor of heat, the body of air between the two walls serves to prevent an excessive loss of heat, due to radiation from the furnace. Across the front is placed an iron casting, called the boiler front, Fig. 43. This contains doors giving access to the head of the boiler for cleaning the tubes, and through the lower doors to the fire, and the ash pit. The grates *g*, Fig. 44, are supported by the brickwork around the fire door and by the bridge wall B. This wall also causes the hot gases to flow up against the bottom part of the boiler, called the crown sheet, and affords a convenient surface against which to bank the fire. The plate on the brickwork at the bottom of the fire door is called the dead plate, and the arch above it the fire arch.

The inner side of the brickwork is lined with fire brick, and when the boiler is placed on the setting the front lugs are bricked in. The rear ones are placed on rollers resting on iron plates to allow for the expansion and contraction due to changes of temperature.

The rear end of the boiler will be placed an inch or so lower than the front, in order that it may drain readily when it is desired to empty it; at the under side of this end is placed the flange for connecting the blow-off pipe.

CHAPTER XIII.

CALCULATIONS FOR FIRE TUBULAR BOILERS.

There are a number of calculations which it is necessary that one should be familiar with in connection with the construction and operation of fire-tube boilers. Those ordinarily required are to find the bursting pressure, safe working pressure, the heating surface, and strength of braces.

We will make these calculations for a boiler the diameter of which we will assume to be 5 feet, length 12 feet, shell $\frac{1}{2}$ inch thick, heads $\frac{5}{8}$ inch thick, having double-riveted longitudinal seams, also single-riveted vertical seams, and containing sixty tubes 3 inches in diameter. The first calculation will be to obtain the bursting pressure of the boiler. It will be necessary to remember that the strength of a boiler or any other piece of mechanism is equal only to that of its weakest point. Therefore, if we find the strength of the weakest point we will be on the safe side.

In such a boiler of cylindrical shape, and having, of necessity, a seam along its length, this will be the point where breakage is most likely to occur, both because of the presence of the seam and because the greatest stress occurs in this direction. Let us imagine ourselves looking at the end of the boiler. There will then be presented to us a circle in which is exerted a force due to the steam pressure.

While the pressure acts equally on all portions of the boiler, it may be resolved into two forces, one a vertical force tending to rupture the shell lengthwise, and the other a horizontal force acting against the heads and tending to cause rupture at the seam connecting the heads to the shell.

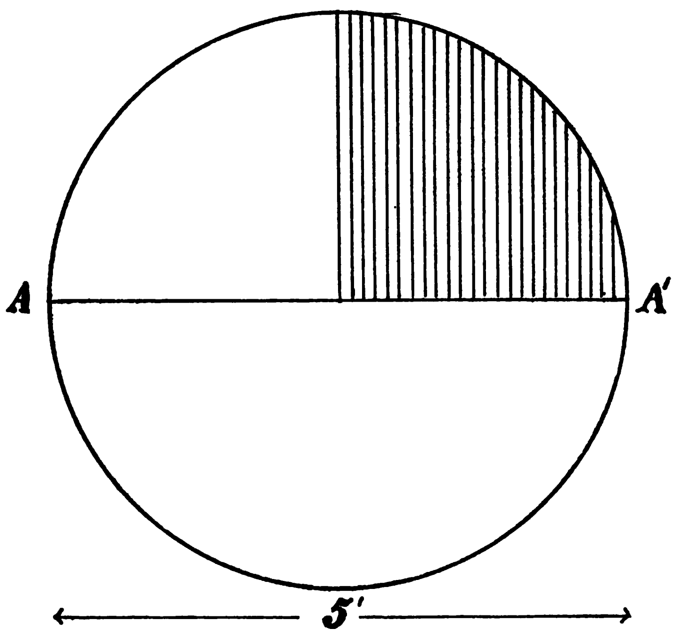


Fig. 45.

As the former can exert pressure only in such a direction as to produce rupture at a point on the lengthwise seam, we may consider the force as acting along a plane equal in length to the diameter of the boiler and tending to burst the shell at the two points A and A', Fig. 45,

where the diameter joins the circumference of the circle.

It may further be considered that only one of these points is liable to be fractured as there is only one seam. Then the forces tending to cause rupture at this point are those acting on the plane from the point A' to the center as indicated by the vertical lines in Fig. 45. Bearing in mind that tensile strength and pressure are both expressed as a certain number of pounds per square inch, we need not consider the entire length of the boiler, but only a strip of it one inch long. We are, therefore, calculating the strain required to break at A' the hoop 5 feet in diameter, 1 inch wide, $\frac{1}{2}$ inch thick, exposed at the given point to a pressure exerted along the plane from the center to A'. The result of this calculation will equal the breaking pressure per square inch for this strip, which pressure is representative of that which may be carried in the entire boiler. If the material of which the boiler is composed is steel of the usual standard tensile strength of 60,000 pounds per square inch, and if the section at A', according to the previous description, is $\frac{1}{2}$ inch thick and 1 inch long, or $\frac{1}{2}$ square inch in area, its total strength will be 60,000 pounds multiplied by 0.5 which will equal 30,000 pounds.

Now, as the distance to this point from the center, or the radius of the boiler, equals 30 inches, then

$$\frac{30{,}000}{30} = 1000 \text{ lb., or } 1000 \text{ pounds per square inch.}$$

So, then, if on each of the 30 square inches represented by the radius of the hoop 1 inch wide and 60 inches

in diameter, there is exerted a pressure of 1000 pounds, the total pressure will equal 30,000 pounds, just equal to the calculated strength at the point A'.

The boiler is, however, weaker than this because in order to rivet the seam it was necessary to drill holes in the material, in which to insert the rivets, and as the cutting away of material for this purpose naturally reduced the effective area of material present, the strength of the material has been correspondingly reduced at this point. Careful investigation has shown that if the original strength of the plate is considered as 100 per cent, then, the comparative strength of the seams are as follows:

Single riveted	56 per cent
Double riveted	72 per cent
Triple riveted	85 per cent

Now, taking our previous pressure of 1000 pounds and multiplying it by 0.72, the strength of our longitudinal seam, the result is 720 pounds, or the bursting pressure of the boiler at this point. Whence we have the rule:

To find the bursting pressure. Multiply the tensile strength of the material by its thickness in hundredths of an inch, divide this product by the radius of the boiler in inches, and multiply by the percentage of strength of the seam.

We must not, however, allow such a boiler to be operated under a pressure of 720 pounds per square inch, as this would not be safe; for the pressure may occasionally rise above that point, and natural deterioration will gradually weaken the boiler. Furthermore,

latent defects may exist which will render it unsafe to operate the boiler at or near the bursting pressure. The safe working pressure of a boiler is determined by dividing the bursting pressure by the factor of safety, which we will assume to be 6. We then have the rule (see factor of safety):

To find the safe working pressure: Divide the bursting pressure by the factor of safety; the result equals the safe working pressure.

We have specified in this boiler that the vertical seams shall be single riveted, and the longitudinal seams double riveted. Because greater strain occurs on the seams along the boiler's length, as shown in the following:

As the strain $= \frac{\text{load}}{\text{area}}$, if we let

P = pressure per square inch
D = diameter in inches
L = length
T = thickness
S = strain,

we have the formulas,

$$S = \frac{\text{load}}{\text{area}} = \frac{PDL}{2\,TL} \text{ for the longitudinal seams.}$$

$$S = \frac{\text{load}}{\text{area}} = \frac{D^2 \times 0.7854 \times P}{D \times 3.1416 \times T} \text{ for the vertical seams.}$$

Solving the equation, we have,

$$S = \frac{PDL}{2\,TL} = \frac{PD}{2\,T} \text{ for longitudinal seams.}$$

$$S = \frac{D^2 \times 0.7854 \times P}{D \times 3.1416 \times T} = \frac{DP}{4\,T} \text{ for the vertical seams.}$$

Substituting the given values for the letters of the formula we have,

$$S = \frac{1000 \text{ lb.} \times 60'' \times 1''}{2 \times 0.5 \times 1''} = \frac{60,000}{1} = 60,000 \text{ lb. for the}$$

longitudinal seam, and

$$S = \frac{DP}{4T} = \frac{60 \times 1000}{4 \times 0.5} = \frac{60,000}{2} = 30,000 \text{ lb. for the}$$

vertical seam.

It will be noted that, in this calculation for strength of longitudinal seams, both ends of the diameter were considered, giving us a total strain on both sides of 60,000 pounds per inch, and that as the vertical seam supports the total pressure exerted on the entire surface of the boiler head it is exposed only to a strain of one-half as much as the longitudinal seams were. It, therefore, does not require so strong a seam to do the work.

As previously mentioned, the heads or flat portions of the boiler, being structurally weaker than the curved portions, require some additional strengthening device beyond that of making them of thicker material.

Where, in a boiler, two flat surfaces are exposed to pressure and are strengthened by bolts passing from one to the other, they are called stay bolts, or through bolts, depending on their length. Where they are supported by pieces of material extending diagonally from the surface at right angles to it, the pieces are called braces. These are made in several ways, the principal ones being those known as the crow-foot braces, on account of the form of the ends where they are riveted to the surface. Sometimes they are called gusset stays. These are simple flat plates joined to the surfaces they

are designed to support, by right angle pieces or brackets, Fig. 46.

The U. S. Marine Rules allow a strain on steel braces

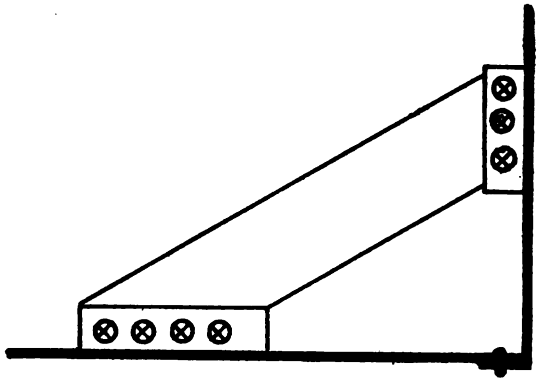


Fig. 46.

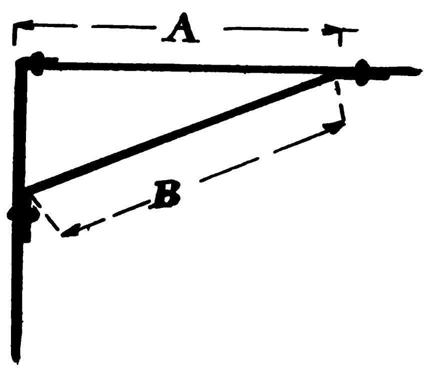


Fig. 47.

of 8000 pounds per square inch in the case of diagonally placed braces. Their strength is calculated according to the following formula (Fig. 47).

$$S = \frac{B}{A} \times P \times A,$$

where A = height of triangle.

B = hypotenuse, or diagonal length.

P = pressure per square inch.

A = area to be supported.

Example: — What strain will there be on a brace supporting a surface 8 inches square, height 23 inches, diagonal length 24 inches, pressure 100 pounds?

Solution: — $\frac{24}{23} \times 100 = 104$ (lb.) $\times 64$ (sq. in.) $= 6656$ lb.

It must be borne in mind that each brace supports an area extending to the limits of the area supported by the other braces. Were the braces spaced 8 inches apart each one would support an area of 64 square inches.

It is not necessary to put in braces for the entire head of such boilers, for the reason that the tubes themselves serve to support a large portion of the head, and the stiffening due to bending at right angles at its edges makes a certain portion of the head of sufficient strength to resist the strain. The amount to be braced will then be approximately the area of the shaded segment, shown in Fig. 48.

In order to find the sizes of the segment we have the following rule:

To find the height of the segment requiring bracing, subtract 5 inches from the distance between the tubes and the highest part of the shell; and to find the diameter of the circle to which the segment to be braced belongs, subtract 6 inches from the diameter of the boiler.

In order to calculate the area of the segment, several convenient methods may be employed which do not

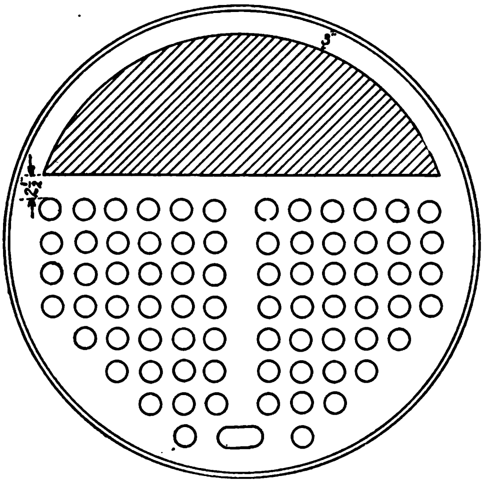


Fig. 48.

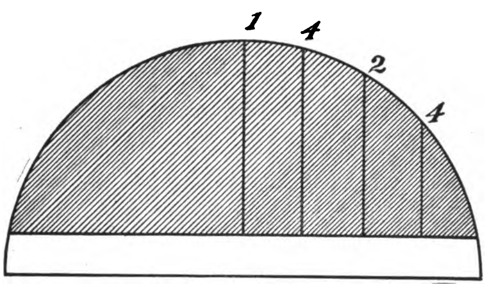


Fig. 49.

require the use of higher mathematics, for example, Fig. 49.

Divide the base of the segment into halves, and divide

one of these halves into four equal parts. Draw perpendiculars through each point of division until they meet the circle and measure each one of the perpendiculars. Then multiply the one at the middle of the segment by 1, the next by 4, the next by 2, and the last by 4; add these products, multiply the sum by the base of the segment, and divide by 12. (The error in this rule, due to the imperfection of the rule itself, and taking no account of error due to imperfection in the measure-

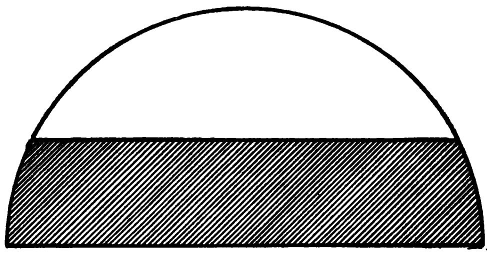


Fig. 50.

ments, is never greater than 1 per cent. In the case of the segment shown the rule is in error by about two-thirds of 1 per cent.)

Or we have as follows, Fig. 50.

Subtract the height of the given segment from the radius of the circle, and multiply the result by the diameter of the circle; this product is to be subtracted from the area of the semi-circle of which the segment forms a part, and the remainder is the approximate area of the segment. (This rule gives an approximate result only when the shaded strip shown in Fig. 50 is approximately a rectangle. The error of the rule amounts to 5 per cent when the height of the segment is 0.272 times

the diameter of the circle. Roughly, we may say that when the height of the segment is greater than one-fourth of the diameter of the circle, the rule may be trusted to give a result within 5 per cent of the truth.)

Instead of taking the shaded area of Fig. 50 as equal to a rectangle having a length equal to the diameter of the circle, we may take it as having a length equal to the base of the unshaded segment, but it is easily shown that the rule obtained in this manner is not quite so close as the one just given.

To find the heating surface of a boiler we have the following rule: Find $\frac{1}{2}$ the area of the boiler shell plus the area of one head; to this, add the product obtained by multiplying the area of one tube by the number of tubes. The result in square feet will equal the heating surface.

It was formerly the custom of various boiler makers to figure the H.P. of boilers by the number of square feet of heating surface. This is an incorrect method of determining such results, because very many conditions of operation, material, etc., may serve to produce varying results with the same boiler. Therefore, the H.P. of boilers is now determined according to certain definite facts, and we have the following rule:

The boiler H.P. is equal to the evaporation of 34.5 pounds of water per hour into steam at 212° F., or the evaporation of 30 pounds of water per hour from a feed temperature of 100° F. into steam of 70 pounds gage pressure. This is equal to 33,305 B.T.U. per hour.

QUESTIONS.

1. What is a steam boiler?
2. Of what materials are boilers made?
3. Describe a horizontal fire tubular boiler.
4. Describe a water-tube boiler.
5. Give some advantages of each.
6. How are boilers fastened?
7. What is meant by the pitch line of riveted work?
8. What is the strength of a seam compared to that of the original plate?
9. Why are the heads of a boiler thicker than the shell?
10. What is the standard tensile strain of boiler material?
11. Give the rule for finding the safe working pressure of a boiler.
12. Find the bursting pressure of a boiler, four feet in diameter, $\frac{5}{16}$ inch shell, with double-riveted seams.
13. What is the safe working pressure of this boiler?
14. If braces are placed 3 in. apart and a pressure of 150 lb. is carried, how much will each brace support?
15. If the braces are 30 in. long, one end being riveted to the boiler shell 25 in. from the head, what area should each brace have?
16. Find the heating surface of a fire tubular boiler 4 ft. in diameter, 12 ft. long, containing 65 two-inch tubes.
17. Of what use is the blow-off and where is it placed?
18. Describe a method of setting boilers.
19. How would you find the area of the shell of a cylindrical boiler 5 ft. in diameter and 15 ft. in length.
20. What would be the area of surface of a 3-inch tube 12 feet in length?
21. What is the area of the head of a boiler 5 ft. in diameter?

CHAPTER XIV.

WATER-TUBE BOILERS.

In the water-tube boiler we reverse to some extent the conditions of handling the fire and the water.

In this boiler the water contained inside the tubes is exposed to the heat of the fire which surrounds the tubes. The immediate result is that small bodies or portions of water are exposed individually to the intense heat of the fire. These smaller quantities are heated to the steaming point more rapidly than the larger amount, in the former case. On this account these boilers are perhaps preferable for power stations subject to sudden demand for increased power, as for instance those supplying street railways, public electric light plants and similar service. While this type of boiler has usually a reservoir or supply outside of the tubes themselves, such as the water drum placed on the upper part of the boiler, yet the entire amount of water in the boiler at any one time is comparatively small, and due to its construction it responds more rapidly to changes of temperature. Consequently if the fire is not constantly maintained in good condition the steam will drop more rapidly than in the fire-tube boiler type of construction. As water is rapidly changed into steam by heating, in the fairly restricted passages formed by the water tubes, scale is more likely to collect in such quantities in the tubes as to produce serious loss in

heating and also to prevent largely the flow of water through them. It is also difficult to remove scale from these tubes.

A number of boilers of this type are of standard construction. Probably among the best known is the Babcock and Wilcox boiler, which is illustrated in Fig. 51.

Reference to the illustration will show us that water entering the boiler at or near the rear and lower end will, being colder, drop down to the lowest portion of the boiler tubes.

The heated gases surround the tubes as shown in Fig. 56. The furnace is generally similar in construction to those previously illustrated, but, in addition, partitions of fire brick are so placed among the tubes, as shown at F, Fig. 51, that the heated gases are caused to travel downward and upward again, thus traversing the tubes several times before making their final escape up the smoke stack. Water thus heated and expanded rises in the direction of the inclination of the tubes until, reaching the front end, it enters the passage called a header, connecting all of the tubes at *b*. From this point it rises into the reservoir shown at the upper portion of the boiler. The particles of water not forming steam flow back along the bottom of this reservoir, and down through the vertical pipes shown, to their original starting point, thus producing a constant flow or circulation in the boiler.

At the lower portion of the tubes and connected to the blow-off pipe is shown a cylinder or mud drum, *c*. The function of this is to collect as much of the scale or sediment as possible while still in a soft state so that it

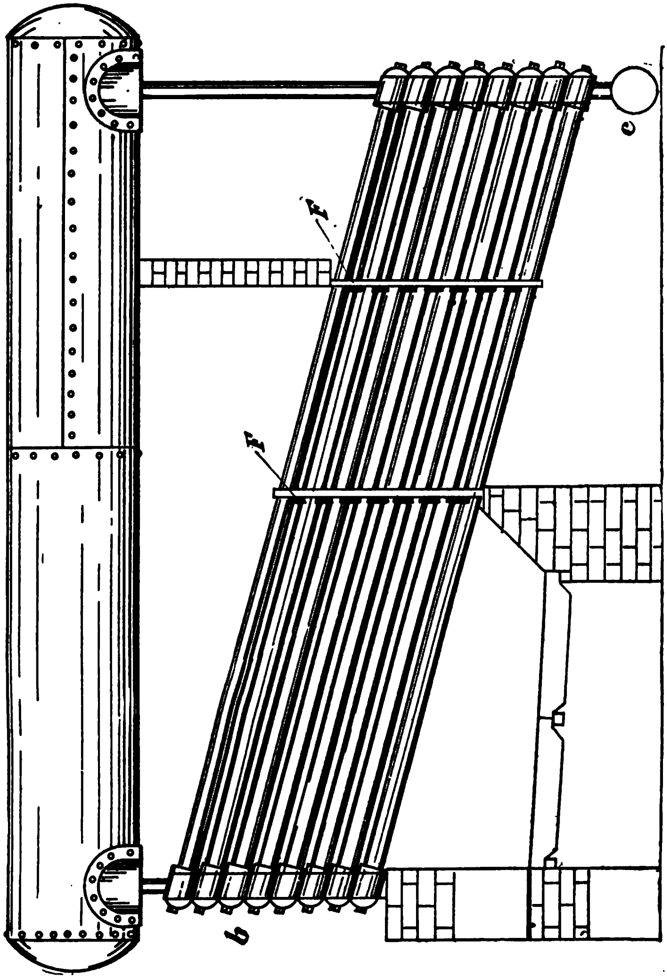


Fig. 51.

may be readily gotten rid of by "blowing down" the boiler.

Steam is taken to supply the engine from the upper cylinder or reservoir. As the steam pipes must necessarily connect at a point near the surface of the water and as there would be a tendency to carry water over into the pipe communicating with the engine, the steam connection is, therefore, made at the rear end of the reservoir or drum, for by the time the steam reaches this point the water will have fallen by gravity back into the main body. Also the baffle plate *b*, Fig. 52, serves to prevent the rush of steam from the header throwing a spray of water into the steam space, by spreading the body of steam and water, as it rises, over the entire surface.

The bolt heads and caps seen on the header opposite the ends of the tubes represent handholes so placed that the tubes may be cleaned by removing the handhole plates in the usual manner and inserting a tube scraper through the opening thus formed. On account of the comparatively small diameter of the reservoir it is not required that they be braced for strength as in the case of the large head of the fire-tube boiler. Additional and sufficient strength is gained in this case by forming them to a hemispherical shape as is clearly shown in Fig. 51.

In the calculation for bursting pressure of the water-tube boiler, the same rule may be applied as was used for the fire-tube boiler, except that, in this case, each tube and the reservoir would be considered as an individual cylinder and its strength would be separately

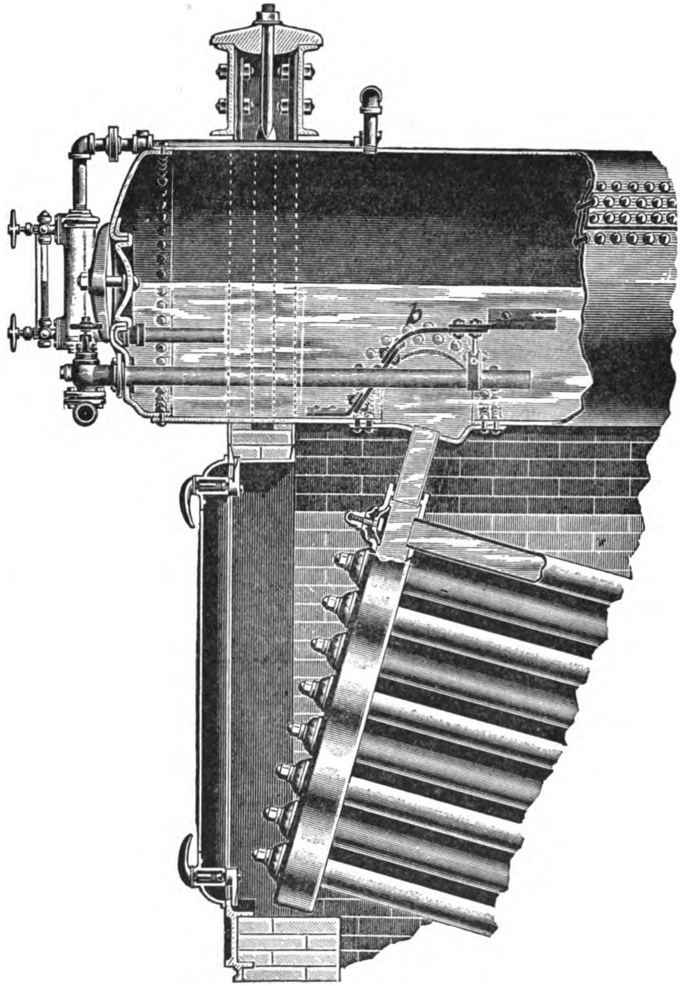


Fig. 52.

calculated. It may be borne in mind, however, that the results of the calculations for bursting pressure of one tube may apply to all.

CARE AND OPERATION OF STEAM BOILERS.

Care should always be taken to supply the boiler with water at as high a temperature as possible. This means that, as the water enters the boiler in an already heated condition, less coal will have to be used to bring it to the steam temperature; also there will be less variation between the temperature in the boiler and that of the incoming feed water. In consequence of this, less strain will be put on the boiler plates and there will be less liability to damage from this source.

The proper point at which the boiler should receive the feed is still a debated question.

Many boilers of the fire-tube type receive the water in the lower part of the front head; some receive it through a pipe passing through the upper part of the boiler for a distance and emptying into the central portion of the main body of water.

In some water-tube boilers the water is taken first into a drum-shaped receptacle where it is partially warmed before entering the boiler proper. One advantage of such a method is that a large amount of the sediment and solid material contained in the water is deposited in one readily accessible place from which it may be removed with facility. This solid material or scale is the source of one of the greatest annoyances to the engineer. Even in apparently clear drinking water large quantities of solid matter are held in solution.

When the water is changed into steam this solid matter is deposited in the boiler, in the form of scale, and forms an incrustation extending over large portions of the boiler, first as a soft mud-like mass and then changing to a hard rock-like formation. If allowed to remain there, this scale is productive of ill results for, being a non-conductor of heat, it interferes with the production of steam. Again, the heat being unable to readily pass through it, the boiler shell may become intensely hot at some point and may be forced out of shape by the internal pressure, producing what is called a "bag" in the boiler. Also, it may be the cause of certain chemical action taking place which gradually corrodes the boiler material, thereby weakening it. This corrosion is usually called "pitting." The deposit of solid matter cannot, of course, be prevented; this is bound to occur. Its accumulation, however, may be prevented by frequent blowing down, at least once a day. When the pressure in the boiler is not high, the blow-off valve should be opened and a quantity of water allowed to escape. This will carry with it a large portion of the sediment which has not yet had time to solidify.

Various means are also employed to keep the scale soft, such as introducing certain chemical compounds, or by supplying the boiler with small quantities of soda through an apparatus similar to an engine lubricator, and a small but constant supply of kerosene. Notwithstanding all such care that may be taken, the boiler should be opened frequently, depending on the quality of the water employed, and it should then receive a thorough cleaning. The scale should be scraped and

chipped loose, then thoroughly washed out by means of a strong stream of water. Handhole and manhole plates should be carefully replaced, the gasket being tightened as described in the section on packing.

Boilers may be tested in two ways. One by hydraulic test, where water pressure, to an amount perhaps thirty per cent greater than the working pressure, is employed. During this test careful observation will note whether any leaks are in evidence. Another and perhaps more satisfactory test is that made by entering the boiler and striking all parts with a light hammer. Any crack or loose portion will be readily detected by the sound, just as a cracked plate can be told from a whole one by the difference in the sound produced when it is struck.

In order to supply the boiler with water, one of two means is usually employed; either by the pump or the injector. In the case of the pump, the cold water becomes warm by passing through the feed water heater.

Occasionally the condensed steam in the form of water is reemployed. In such a case care must be taken to separate the oil, which the steam accumulated in passing through the engine cylinder, from the water before sending it again into the boiler. For if oil were allowed to enter the boiler it would coat the inner side of the metal with a thin film which is as bad as the scale itself.

In starting a new fire under a boiler, sufficient time should be taken to allow the boiler to heat up gradually and adjust itself to the new conditions. Rushing the fire will cause such a rapid expansion of the boiler material as possibly to develop some latent faults in its

construction which would not have become evident had the heat been generated slowly.

The fire should be kept even and thoroughly burning at all times, in order to maintain a constant pressure, because a variation of pressure produces a constant variation in the expansion of the boiler shell which tends, in time, to weaken it.

The fire should not be allowed to die out in spots, as this allows cold air to enter, not only reducing the temperature of the heated gases but, while killing the surrounding fire, allows cold drafts of air to strike the boiler shell. If the plant is to be shut down in the evening and operated again in the following morning, it is best not to allow the fire to die out entirely. This is prevented by what is called banking the fire.

To bank the fire, a short while before it is time to shut down, a quantity of fresh coal is thrown on and the fire doors are closed for a period sufficient to allow the new coal to become well ignited. Then the clinkers are thoroughly broken up and they, together with all ashes and waste material, are drawn out of the fire, leaving on the grates only the fresh coal, which was thrown on shortly before. This is pushed against the bridge wall and across the rear portion of the grates. It is now covered with a quantity of fresh coal until no glow from the burning coals may be observed. This leaves the front part of the grate open and clear.

After disposing of the ashes, the ash doors and damper are closed and the fire doors are left partly open. As a result, the fire smoulders gently throughout the night. In the morning there is present a bed of glowing coals

which requires only to be spread over the grate, covered with fresh coal and then the draft placed in operation. This will produce a good fire in a very short time. This also has the added advantage that the temperature has not gone down too far during the night. The water in the boiler has been kept warm so that steam may be raised quickly.

As a proper and constant supply of oxygen is necessary to maintain complete combustion in the furnace and as the amount of heat supplied will vary with the demands on the boiler, some means is required for the regulation of the draft. This may be done by means of the fire and ash-pit doors, but it is generally considered bad practice to do so; for, besides the constant attention required, opening the fire doors, to allow cold air to enter, reduces the fire, chills the boiler and the surrounding brickwork, and is liable to crack the brickwork and injure the boiler, besides being expensive in the use of coal. A better and more efficient means of regulation is that of the damper which, though larger, is operated on the same principle as the damper of a kitchen stove, being merely a plate so arranged in the chimney that it may be swung lengthwise with, or across, the opening. To maintain an even pressure, damper regulators are employed. The essential principle of a damper regulator is a piston operated upon by steam from the boiler. If it is desired to maintain a pressure of 80 pounds per square inch, the piston will be so weighted that, when steam in the boiler to which it is connected rises to 80 pounds, the piston will move upward in its cylinder. If now the piston-rod is connected to the

lever operating the damper in such a manner that, when the piston rises, it closes the damper, then, when the pressure reaches the desired point, the draft will be automatically shut off. When the pressure decreases, the weights will force the piston down, thus opening the damper more or less and in this way a constant regulation of the air will be maintained, and likewise a constant pressure of steam.

It is of extreme importance that the engineer should know the height of the water in the boiler, for if any of the parts directly exposed to the heat of the fire should be uncovered they would quickly become red hot and give way, due to the pressure upon their surfaces, or, if fresh water were supplied, the sudden change in temperature would cause a rupture of that particular part and a boiler explosion would be the result. In fire-tube boilers of the horizontal type it is customary to specify that the water level shall always be at least three inches above the highest row of tubes. In order to maintain the proper level, boilers are supplied with water columns; this is essentially a tube or box of iron connected by means of pipes to the upper and lower parts of the boiler proper *a*, Fig. 53. With the connecting valves open, similar conditions exist in this water column as in the boiler, consequently water rises to a level equal to that in the boiler itself. The water column is supplied with three small valves, one placed at the point where the greatest height of water is carried, one at the lowest point and one between the other two. By opening these valves the engineer may judge of the height of water in the boiler. If, for ex-

ample, on opening the valves there issues a stream of hot water from the lower one, from the upper one a stream of vapor, and from the middle one a mixture of water and steam, we know that the water level is close to the central point. In order to determine quickly and exactly the height of water, the water column is supplied with an auxiliary column connected to it at the top and bottom and is called a gage glass, *b*, Fig. 53. This is a glass tube in which, for reasons previously given, the water will rise to the same height as in the boiler and water column proper, and the engineer may know at a glance exactly its position.

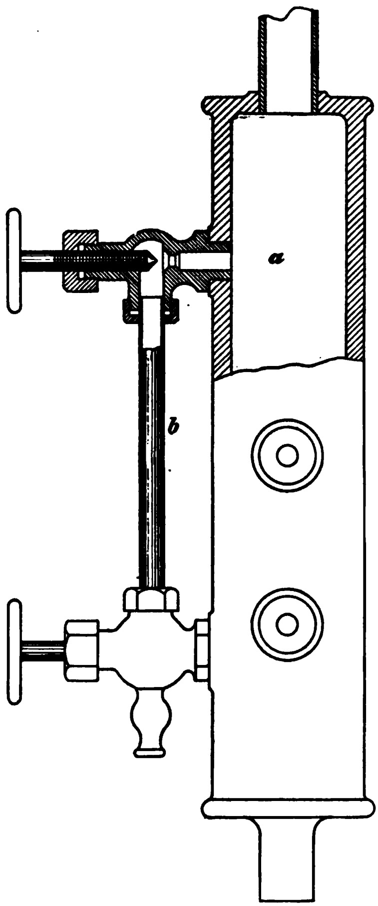


Fig. 53.

These glass tubes are held in position by small stuffing boxes packed with rubber washers. They are supplied with a valve at either end. Should the

glass tube break (which is apt to occur), the bottom valve should be shut off first because the hot water will scald, while the dry steam will not. After replacing the tube, the upper or steam valve should be opened first in order gradually to establish the pressure in the glass before allowing the water to enter. This will reduce the possibilities of again fracturing it.

Should the water at any time disappear from the gage glass so that its height is unknown, fresh water should not be supplied to the boiler as some of the tubes may have been uncovered. The fire should be drawn, the boiler allowed to cool down and an internal inspection of the boiler made before going ahead. When pressure is on the boiler and it is desired to open the valves this should be done slowly. A valve under pressure should never be opened quickly, on account of the liability to damage, due to the possible sudden shock.

STEAM GAGE.

In order to know at any time just what the pressure in the boiler is, the steam gage is employed. To illustrate the principle of this gage, we might take a bit of rubber tubing, circular in cross section, and bend it to form a circle. If we observe the section of the tube under these conditions we will find that it is no longer circular, but oval in form. If we try to bring this oval back to a round form we can do so only by straightening the tube.

On this principle our steam gages are built, Fig. 54. A metal tube, closed at one end and having the other end fixed to some convenient means for attaching to a pipe

leading from the steam boiler, is bent to a circular form. If now steam is allowed to enter this tube it will tend, as the pressure increases, to change the cross-section form of our tube, which will try to straighten, the closed end moving more or less according to the pressure exerted. If now a needle or pointer be pivoted in some suitable manner so that it may be caused to revolve by pulling it around, and one end be so connected to the closed end of our curved pipe that when the pipe

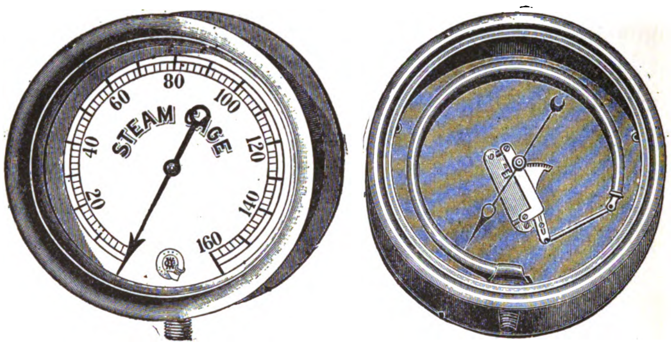


Fig. 54.

moves, due to increased pressure, it will pull the needle around, the amount of movement of the further end of the pointer passing across a properly graduated scale will indicate the pressure in pounds per square inch in the boiler. As the bent tube is essentially a spring and as the permanent accuracy of the instrument depends upon its retaining its temper, we try to prevent its loss by not allowing the hot steam to come in direct contact with the spring tube. This is accomplished by connecting it to the boiler through a pipe so bent or

curved as to form a trap where any water collects, the water being acted upon by the steam and, in turn, acting on the curved tube.

This bent connecting pipe is called a goose neck.

FURNACE GRATES.

Boiler grates are made either fixed or movable. The material is cast iron. In either type they are made in comparatively small sections, to enable replacements to be readily effected. The fixed bars will serve as an illustration of the shape of all bars, Fig. 55.

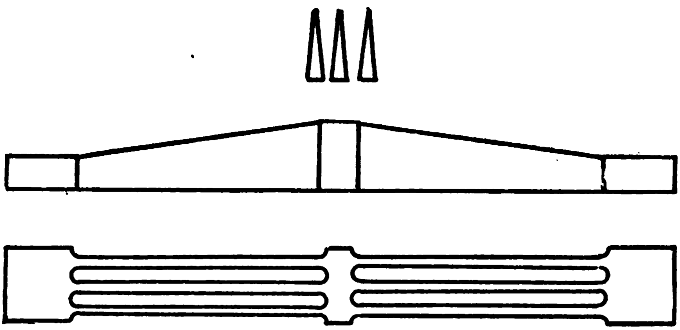


Fig. 55.

It will be noted that the cross-section area is deep and narrow. This form provides large surface for radiation, so that the incoming air becomes fairly warm before reaching the fire and keeps the grate in a comparatively cool state by absorbing its heat.

While fixed grate bars possess the advantage of readily holding the coal on a level surface, there is always some difficulty in cleaning the fires and removing the ash and clinkers.

To facilitate the breaking up of clinkers, moving or rocking grate bars have been introduced. They are made in sections, as are the others, but the ends are pivoted and connected to a lever projecting beyond the boiler front, in order that they may readily be moved, thus breaking up the hard clinkers and causing more or less sifting of the ashes. It is important that the ash pit be kept clean, for if ashes are allowed to accumulate they will prevent free circulation of air below the grates, which, in consequence, will soon become red hot and be ruined.

While hand firing is still continued in many plants, in large plants it is sometimes economical to use some means for automatically supplying the furnaces with coal. For this reason automatic stokers were designed and introduced. These take many forms, among the principal ones being that of a piston, which, moving backward in a cylinder, allows a supply of coal to drop in front of it, and being forced forward, the coal is moved into the furnace. In others, the coal, kept in a hopper in front of and above the fire doors, is allowed to drop down on the upper part of an inclined grate, and gradually carried downward by a shaking or rolling movement of the grate until, reaching the lower end, it has been entirely consumed and drops off in the form of ashes. The object of these methods of automatic firing is to coke, or gradually heat, the coal to the burning point, so as to present a small continuous burning body of fuel which enables thorough combustion to take place, and then to get rid of the residue, all in a systematic and progressive manner.

The burning of coal dust has been tried in several ways, principally in the form of briquettes, where coal dust is held by a suitable binder of tar or similar material, and also by blowing a çonstant stream of the dust into the furnace where it is immediately consumed. As this latter form would be difficult to maintain in a burning condition if the coal dust alone were supplied, the heat for burning it is produced by a small body of coals burning on the grate in the ordinary way.

Where oil is used for fuel greater cleanliness is the natural result, as there are no ashes, the oil being allowed to enter the furnace through burners and, under pressure, there consumed.

Where blast-furnace gases are employed, the gas is ignited, and combustion is maintained by a small quantity of fuel burning on the grate as previously described.

In starting the fire in a cold boiler it must be kept in mind that the steam space, or space free of water above the water line, contains air. As the temperature of the water rises, and steam begins to form, this air must be removed. In order to do this we open the upper valve on the water column. The air escapes through this until it has all gone. This will become evident by a stream of vapor issuing from the valve nozzle. At this point the steam space has become filled with steam at the same pressure as the atmosphere, consequently no indication is shown on the steam gage.

When the pressure begins to rise the steam begins to register in pounds pressure above the atmosphere. The pressure registered on the gage is called the GAGE

PRESSURE. The gage pressure, plus the atmospheric pressure, is called the ABSOLUTE PRESSURE.

Water should not be carried at too high a level in the boiler. If this is done the steam space will be so small that the main pipe will take up steam in a saturated condition. This is likely to give a false height to the water line, as the water will run up and down, owing to the pull on the steam line. This reduces the pressure on the water, and the water, as a consequence, may be carried over into the engine. This is called PRIMING.

Occasionally, if the boiler is being forced or the water is dirty, a surging of water up and down in the water column will be observed. This is called FOAMING and may be remedied by the obvious method of easing up the work on the boiler, lowering the water level or cleaning out the old water and getting new. The water column, pipes and connections should be supplied with suitable means for blowing them out frequently in order to prevent an accumulation of scale which may give us a false water level.

When two boilers are to be connected while running, care must be taken in opening the valves and in making the connection very slowly until an equilibrium of pressure is established. It is better to have the pressure nearly alike in both boilers before connecting.

If two boilers, one having a pressure of 70 pounds and the other a pressure of 30 pounds are connected, after the valves are open the pressure in both boilers will be 70 pounds, but the water level in that originally having the lower pressure will rise slightly. This is due to the condensation produced by the hot steam from the higher

pressure boiler coming in contact with the lower temperature water in the lower pressure boiler.

CHIMNEYS.

Draft for maintaining combustion may be supplied in two ways: natural draft, due to the current of air rising through the smoke stack or chimney; artificial draft, produced by means of a blower of suitable size and form which will force the air through the fire under pressure.

Each pound of coal burned produces from 15 to 25 pounds of gas. The gas carried off by the chimney in a given time depends upon three things: the size of the chimney, velocity of the flow and density of the gas. The density decreases as the temperature increases. Experiment has shown that a temperature of 550° F. above the surrounding atmosphere may conveniently be used as a basis for calculation.

Necessary calculations for chimneys may be made by employing the following formulas:

Where H.P. = horsepower of boiler.
H = height of chimney in feet.
E = effective area in square feet.
A = actual area in square feet.

Then,

$$H.P. = 3.33\,E\sqrt{H}.$$

$$H = \left(\frac{0.06\,H.P. \cdot 5}{E}\right)^2.$$

$$E = \frac{0.3\,H.P.}{\sqrt{H}}.$$

$$A = \frac{0.35\,H.P.}{\sqrt{H}}.$$

There is a difference between the actual and effective areas because of a retardation of velocity due to friction against the walls, the layer of gas thus affected is about 2 inches thick over the entire interior of the chimney.

There are many conditions which affect the action of chimney draft. The first to be considered is the question of fuel. In some parts of the country only bituminous coals are burned, which requires a large air supply. In other parts, anthracite coals are mostly used. The rate of combustion per square foot of grate surface per hour has been found to vary from 8 to 15 pounds with anthracite coal, and from 12 to 25 pounds with bituminous coal. It is generally conceded that the combined efficiency of the boiler and furnace falls off rapidly with an increased rate of combustion. It is customary to consider that the average temperature of the air supplied to a furnace is 62° F. At this temperature the air occupies a volume of about 13 cubic feet, per pound of weight. Theoretically, perfect combustion requires about 12 pounds of air to 1 pound of the products of combustion, or 13 pounds altogether, but in practice it is nearer 25 pounds of waste gas that is carried away by the chimney. Chimney draft is the result of the difference in the specific gravity of the cold air brought into the furnace and the specific gravity of the waste gases passing up the chimney. This difference is produced by the expansion of the gases on account of the heat. The question of height is also an important factor. The height of a column of expanded gases in the chimney, and the difference between the specific gravity of a given volume within and a given

volume of cold air outside, governs the draft of the chimney. It may seem that the draft begins at the base of the chimney but, in reality, it begins where the supply of cold air first reaches the fire and is expanded by the heat. It is evident that the question of temperatures in the chimney is an important one, since the greater the heat the more the gases in the chimney will be expanded and the more they are expanded the less will be their relative specific gravity. From 450 to 500 degrees is about the minimum temperature for escaping gases in practice. The temperature of the gases, as well as the height of the chimney, must, therefore, regulate the velocity of the flow of air through the furnace. In ordinary practice one half inch draft, as shown by the pressure gage, is all that is required, but with the small sizes of anthracite coals a greater intensity is required.

The draft in a chimney is caused by the difference in weight of a column of hot gas in the chimney and that of a column of the outside air of the same height. For example, let us assume the gases in the chimney to be at a temperature of 500° F. and the outer air at 62° F. The weight of a cubic foot of air at 62° is 0.0761 pound, and at 500° it is 0.0413 pound, a difference of 0.0348 pound. Therefore in a 100-foot chimney there would be on each square foot of its area an upward pressure of 0.0348 pound times 100 or 3.48 pounds.

Now, as a cubic foot of water at 62° weighs 62.32 pounds, a column of water one foot square and one inch high will exert a total pressure of 5.193 pounds or 0.577 ounces per square inch.

The draft will, therefore, equal $3.48 \div 5.193 = 0.67$ inch of water or about 0.39 ounce pressure per square inch. However, we have in the chimney a mixture of gases, due to the combustion of the fuel, which are not of the same specific gravity as air and varying with the quality of the fuel; using a good quality of anthracite coal and with complete combustion, other conditions remaining as previously stated, the draft in inches would be about 0.62 of an inch.

INCRUSTATION AND SCALE.

Nearly all waters contain foreign substances in greater or less degrees, and, though this may be a small amount in each gallon, it becomes of importance where large quantities are evaporated. For instance, a 100-H.P. boiler evaporates 30,000 pounds of water in 10 hours, or 390 tons per month; in the comparatively pure Croton water there would be 88 pounds of solid matter in that quantity, and in many kinds of spring water as much as 200 pounds.

The nature and hardness of the scale formed out of this matter will depend upon the kind of substances held in solution and suspension. Analysis of a great variety of incrustations proves that carbonate and sulphate of lime form the larger part of all ordinary scale, that from the carbonate being soft and granular, and that from the sulphate, hard and crystalline. Organic substances in connection with carbonate of lime will also make a hard and troublesome scale.

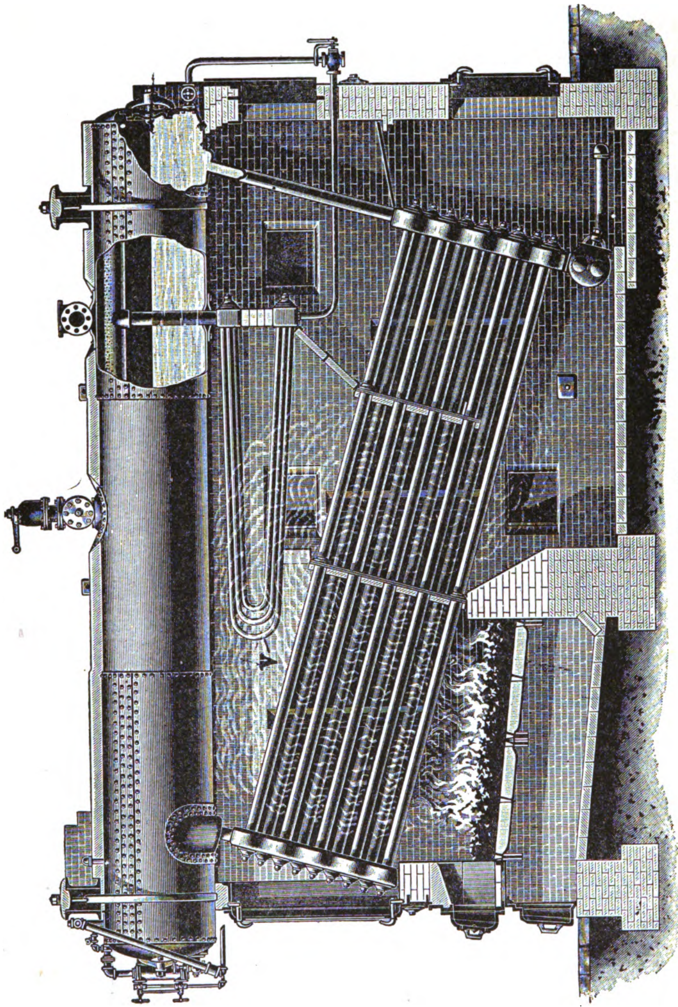


Fig. 56.

SUPERHEATED STEAM.

It is shown elsewhere that many losses are bound to occur in the use of steam. One of the best means of partially preventing this loss is by the use of superheated steam. Steam is said to be superheated when, at any given boiler pressure, it has a higher temperature than the water from which it was evaporated. Water cannot exist in the presence of superheated steam for it is itself evaporated into steam.

While the temperature of saturated steam cannot be raised without increasing its pressure, the temperature of superheated steam, allowed to expand, may be raised without increasing the pressure. Expansion is provided for by the steam being drawn off and used. The superheater shown at *V*, Fig. 56, is designed to fulfil these conditions and is placed in such a position as to insure the steam receiving from 100° to 150° F. of superheat. It consists, as will be seen, of a number of tubes bent into a U shape and connected at both ends by pipes called manifolds, through one of which steam is received from the boiler; through the other the superheated steam, after passing through the tubes, is collected and delivered to the valve placed above the boiler.

SAFETY VALVES.

After having built and placed the boiler in position and having equipped it with water column, steam gage, etc., it is necessary to supply a safety valve as an additional precaution against generating too much pressure, because conditions are apt to occur when the pressure will rise far above the normal amount required.

For this purpose there is installed on the upper portion of the boiler the safety valve, which is designed to be so adjusted that it will remain closed until a predetermined amount of pressure per square inch is produced. Then it should open and allow steam to escape in sufficient quantities to prevent a further increase in pressure, and it should close again when the steam has dropped below the normal pressure. These valves are of three kinds, known as the *dead-weight, spring*, and *lever safety valves*. The dead-weight valve, which is seldom used, consists of a valve seat with a disc resting on and closing the opening, upon which are placed weights, equal in amount to the total pressure exerted on the valve disc, when the pressure reaches the normal point. For instance, were the diameter of the opening 3 inches, the area would be approximately seven square inches. If the normal working pressure at which it is desired the valve should open is 100 pounds per square inch, it would therefore mean a total pressure of 700 pounds which would have to be opposed by an equal weight of metal placed upon the valve. This is evidently too awkward and cumbersome a method for ordinary use. On locomotives and other engines, subject to vibration, and in fact on many stationary boilers, the spring safety valve is employed, Fig. 57.

In this case, the disc *a* rests upon and tightly closes the opening of the seat *b*. The pressure from the inside of the boiler pressing up against and tending to lift the disc is opposed by the spring *c*, the pressure of which is adjusted and maintained by the screw *d*.

When the total pressure represented by the normal

pressure per square inch on the area of the disc is reached, the disc rises and allows steam to escape through the body of the valve out of the opening *e*. In order to prevent the sudden opening of the valve and consequently a loud screech, produced by the steam at that time, the small openings *f* and *f* are so placed

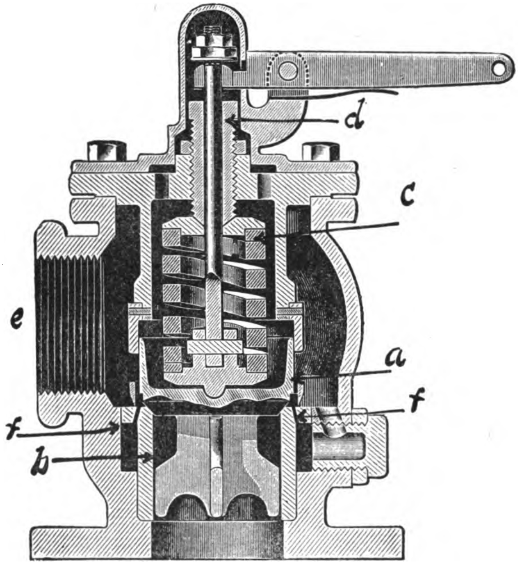


Fig. 57.

that, before the valve entirely opens, a portion of the steam escapes through *f* and *f* into the body of the valve and thus equalizes the pressure. All safety valves should be directly connected to the boiler; that is, no other valve of any kind should be placed between the safety valve and the boiler as it is always possible that such valves may be inadvertently closed, thus

rendering the safety useless. The third type or lever safety valve, illustrated in Fig. 58, is very largely used for boiler work on account of its convenient form. It consists, as before, of the seat and disc; rising from the disc is the stem and pressing the stem and disc into position is the lever pivoted at one end and weighted at the other. Any change of position of the weight

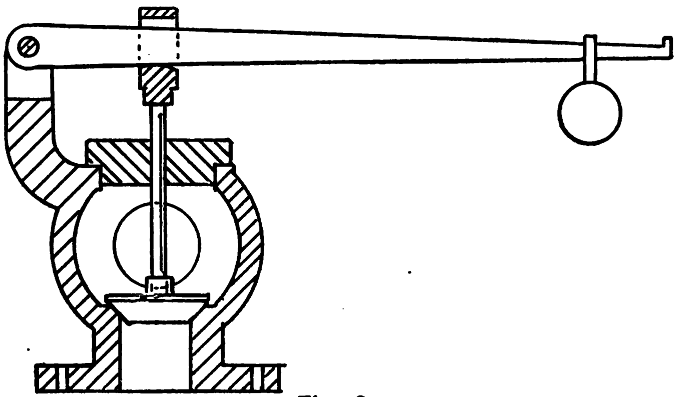


Fig. 58.

varies the pressure upon the disc and consequently such a valve is capable of a wide range of adjustments.

The method of calculation for the lever valve is the same as for levers of any kind. This valve is a lever of the third class because the power is exerted between the fulcrum or pivotal point and the weight. The total pressure exerted on the surface of the disc is sometimes spoken of as the power.

The distance from the fulcrum to the point where the valve stem touches the lever is called the power arm. In all such calculations the length of the power arm,

multiplied by the power, equals the length of the weight arm, multiplied by the weight in pounds. Therefore in order to ascertain any one of the four factors, the other three being known, it is only necessary to multiply the two known factors on one side and divide by the known factor on the other and the result will be the answer.

Example. — Find the weight, which, placed at the end of a lever 24 in. long will allow a safety valve 4 in. in diameter to open when the steam pressure has reached 100 lb. per sq. in., the power arm being 3 in. long.

4 in. diameter = 12.56 sq. in. 100 lb. per sq. in. × 12.56 sq. in. = 1256 lb. total pressure.

$$\text{Ans.}\quad \frac{1256\text{ lb.} \times 3\text{ in. power arm}}{24\text{ in. weight arm}} = 157\text{ lb.}$$

Similarly any one of the other factors may be determined. The valve seats are made either flat or angular. In flat-seated valves the amount of opening may be readily determined by multiplying the diameter by the constant 3.1416, which gives us the circumference, and multiplying this product by the lift; for example: Our 3-inch valve has a circumference of 9.42 inches. If the valve lifts $\frac{1}{2}$ an inch, the amount of opening equals 4.71 square inches. If the valve lifts an amount equal to $\frac{1}{4}$ of its diameter, the area of the opening is equal to the area of the surface exposed to the pressure of the steam.

The angular valves may be calculated as follows: First, multiply the diameter of the valve by 3.1416, and also by the lift and by the sine of the angle of the seat; call this product (1). Then multiply the square of the lift by the square of the sine of the angle of the seat, by

the cosine of the angle and by 3.1416; call this product (2). Add products (1) and (2) and we have the amount of opening required.

In order to find the area of opening, given by the lift of a valve of 45° bevel and the valve lift being above the seat, we use the following rule:

Multiply the diameter of the opening in inches by the depth of the seat in inches and then multiply the result by 0.707, and call this product (1). Then multiply the square of the depth of the seat by 0.499849 and the result by 0.707, and call this product (2). After this, multiply that part of the lift of the valve above the seat by the diameter of the valve opening, and call this product (3). Then add together the three products and multiply their sum by the constant 3.1416, and the result will be the area of opening expressed in square inches given by the lift of the valve above its seat.

It is necessary that the maximum opening of the valves be sufficient to allow free exit for the steam.

The rule formerly employed was to allow one half of one square inch of the valve opening for every square foot of grate surface. This rule, however, is not entirely correct, as the amount of steam generated, heat of the fire, and other conditions tend to affect the results, and the following rule should be employed:

To find the diameter of a safety valve for a given boiler we use the formula,

$$D = 0.0086 \frac{E}{I} \times P,$$

where D = the diameter, E = evaporation per hour in pounds of water, I = lift of valve in inches or fraction

of an inch, P = absolute pressure on the boiler in pounds per square inch.

It is advisable that the valve lever be lifted and the valve opened at least once a day, preferably when the pressure is low, in order to be certain that the valve is in good working condition. For if this is not done, corrosion is apt to take place and the valve may become stuck, thereby being useless when its services are required.

No additional weights should be placed upon the valve lever other than those properly provided and adjusted. Neither should it be tied down in any way or at any time.

QUESTIONS.

1. Describe the damper.
2. Sketch and describe the water column and gage glass.
3. How should they be connected to the boiler?
4. Sketch and describe the operation of the steam gage.
5. How may coal be supplied to the fire?
6. What is gage pressure, absolute pressure?
7. How should boilers under pressure be connected?
8. Find the actual, and the effective areas of a chimney 100 ft. high for a boiler of 250 H.P.
9. How high should a chimney be for a boiler of 400 H.P. if the effective area is 12 sq. ft.?
10. Find the H.P. of a boiler which may be used if the chimney is 100 ft. high, and has an effective area of 7.76 sq. ft.
11. How would you find the cross-sectional area of a 3-in. tube?
12. What is scale?
13. What is superheated steam?
14. Describe the safety valve and its use.
15. What diameter safety valve should be used on a boiler having a working pressure of 100 lb. with a weight of 60 lb. suspended 36 in. out on the lever, the power arm being 3 in. long?

16. What weight placed 24 in. out on the lever will allow a 3-in. valve with 2-in. power arm to open at the pressure of 80 lb. per square inch?

17. What is priming or foaming?

18. What is the result if scale accumulates in the boiler?

19. What injury is this liable to produce?

20. What should be the diameter of opening of a flat-seat safety valve on a boiler running with 100 lb. absolute pressure, $\frac{1}{8}$ in. lift of valve, the boiler evaporating 3000 lb. of water per hour?

CHAPTER XV.

PUMPS.

Steam pumps for supplying boilers are really a sort of combination steam engine and pump. Briefly, they consist of a slide valve engine on one end of the frame with the usual piston and piston-rod, but without the connecting rod, crank and crank shaft. The piston-rod is continued and extended into another cylinder opposite the steam cylinder, and there fastened into a piston of slightly different form and size which pumps the water. The piston on the water end is called a plunger. Pumps are usually made single or duplex. In the case of the latter, it consists of two complete engines and pumps combined as one. The cross section of a steam pump is shown in Fig. 59. On one end will be noted the steam engine similar in construction to those previously described and having the piston-rod p and the valve-rod r in the usual positions. This portion of the pump requires no description. Passing to the further end, the piston-rod is connected to the plunger g, working in the cylinder c, which forms a portion of the main chamber h. There will be noted in this end of the pump, four valves v, v^1, v^2, v^3. These are held in position on their seats by the springs shown somewhat more clearly in Fig. 60, and the source of water supply, passing through a proper pipe, allows the water to flow to the point e. Assuming now the piston to be moving from right to

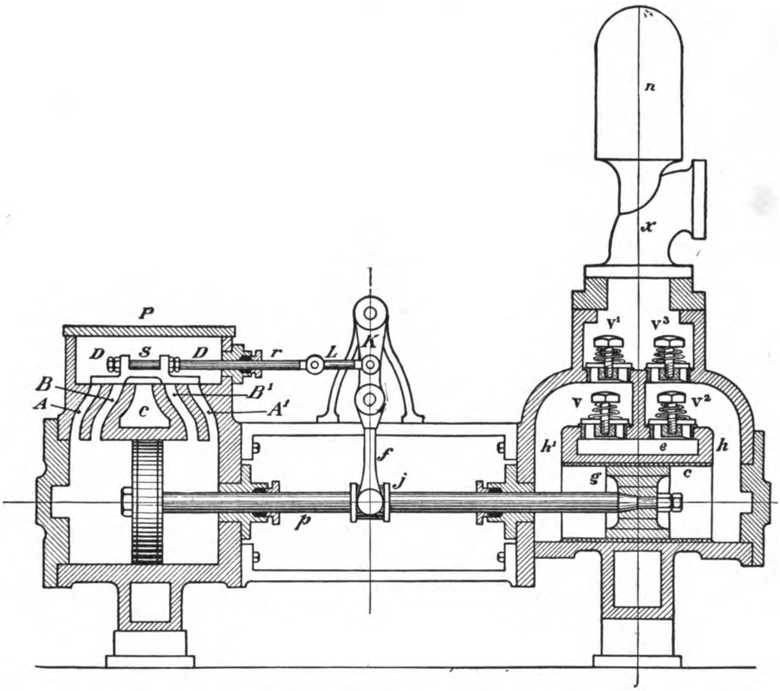


Fig. 59.

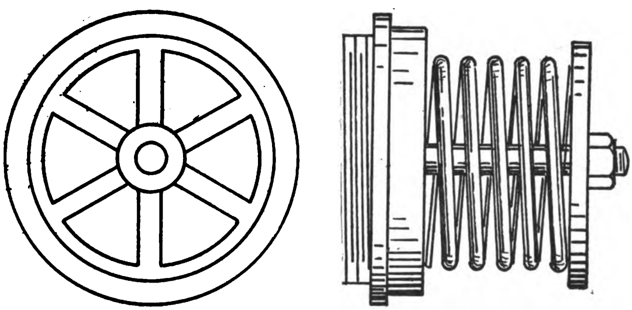


Fig. 60.

left a partial vacuum is produced in the right-hand end of the chamber *h*. The water at *e*, which is, of course, under atmospheric pressure at least, now enters the chamber *h* by lifting the valve v^2 against the pressure of the spring and fills the entire space. On the return stroke the plunger, moving now from left to right, produces a similar vacuum in the other end of the chamber, which is filled, as in the previous case, by water passing from *e* to *h′*, through the valve *v*. The water which filled the right-hand end of *h* during the previous stroke is compelled to find its way out through the upper valve v^3 on that side, through the pipe *x*. It cannot flow back the way it came, into *e*, because the greater pressure it exerts the more tightly it closes the valve v^2 just like a trap door, and consequently it can find an exit only through the upper valve. The next stroke will continue in the same way drawing water again into the right-hand side of *h*, and supplying another quantity of water to *x* through the upper valve v^1 on that side. As there would not be a constant flow of water, due to the slight interval of rest between the strokes, this is provided for by the air chamber *n*. When the water is forced up into the pipe on the first stroke, a portion of it enters and partly fills the chamber *n*, compressing the air which it contains. During the interval between one stroke and the next, when the flow of water might cease, the air, previously compressed in *n*, expands and forces out the water which entered the chamber during the previous stroke. This process being repeated produces a continuous flow of water through the pipe.

The connections of the water end of the pump are

made so that the delivery line is larger than the suction or supply line. The place of an eccentric in such a pump is taken by the rods and links *f* resting in the collar *j* on the piston-rod. As the piston moves forward the rod moves with it and a similar rod on the opposite end of the shaft moves also and changes the position of the slide valve for the other half of the pump. When the other half of the pump moves, it shifts, in a similar manner, the slide valve *s*, by means of the rod and crank *k*.

As the pump is required to supply water to the boiler from which the steam operating the pump is supplied, it is evident that with a pressure of 100 pounds per square inch, to do the work, if the water cylinder were of the same diameter as the steam cylinder, the pressures would be balanced, to say nothing of the additional work required in lifting the water and overcoming the friction in the pipes. On this account, the steam cylinder is made larger in diameter than the water cylinder, thus gaining sufficient additional total pressure to enable it to do the work.

DUPLEX PUMPS.

The valve mechanism and the setting of the same on the duplex pumps are the simplest of all forms of pump construction.

In most cases the valves are of the plain D type of slide valve, with practically no steam or exhaust lap. Some slack must be left between the driving nuts on the valve stem and the yoke of the valve to allow the left-hand piston to nearly complete its stroke before the

valve on the right-hand piston begins to admit steam; in other words, this slack must be at the proper distance to make one piston start just before the other comes to rest; otherwise the principal object in a duplex pump — that of having a continuous flow of water — would not be attained. As a rough rule, this distance between the valve stem nuts and the yoke of the valve should be the width of one steam port.

Referring to Fig. 59, it will be noticed that there are two sets of steam ports or five ports altogether, two steam ports A, A′, two exhaust ports B, B′, and one exhaust cavity C. The object of this arrangement is to cushion the piston on the completion of its stroke, this being accomplished by the piston passing port B, which has been exhausting steam, and as port A is covered by the valve at this time, the remaining steam in the cylinder will be compressed, thus cushioning the piston and preventing it from striking the cylinder heads.

Setting the valve on a duplex pump is accomplished as follows:

Place the two pistons exactly at mid-stroke as in Fig. 59. Then adjust the valve stem nuts D and D so that when the valve is in a central position, just covering the ports A and A′, the slack between the nuts D and D and the yoke on the valve will be the same on either side and the combined slack between nuts and yoke will be equal to the width of port A. Set the valve on the opposite side of the pump the same way.

In this pattern of pump the steam is admitted at the side of the steam chest so that the steam chest bonnet P can be removed and the nuts D, D adjusted without

breaking the steam connections. In other patterns the nut D is a single nut placed between the parts of the yoke. In such a case you have only to disconnect the link L and turn the valve stem to the right or to the left. This screws the stem into or out of the nut. The distance between the nut and the yoke cannot be altered without adding to or taking from the thickness of the nut.

PUMPING HOT WATER.

Simply stated, hot water must flow to a pump. Vapor rises from water even if it is not of a temperature sufficiently high to be called hot water. Referring back to the description of a suction pump, it will be readily seen that, if vapor is rising from the water, the vacuum will be wholly or partially destroyed and the suction chamber will not completely fill with water because the space is already filled with vapor. The effect of this is greater because water boils and vaporizes at a lower temperature in a vacuum than it does under pressure. It is generally considered that a temperature of 190° F. is the limit for attempting to raise water by suction. The height to which hot water will be raised by the suction can be found by determining the amount of vacuum in the suction chamber. It may be laid down as a general rule that, in order to have a pump handle hot water without trouble, the supply should be delivered under pressure or be above the pump and that it should work at moderate speed. Metal valves are also preferred to soft rubber or similar valves. Gun metal, clack, and ball-check valves have been used to advantage for this purpose.

THE WATER END OF A PUMP.

In the design of a steam pump, the capacity of the water end should be calculated on the consideration of piston speed and upon the time allowed for the valve to open and close. It is patent that if sufficient time is not allowed for the proper opening and closing of the valves, the slip will be large and the pump will consume considerable power in doing useless work. The general rule has been laid down by most authorities that 100 feet per minute is the limit of piston speed in order to give the water valves the proper time to open and close. It has been found, however, in practice, that for some designs, even 100 feet per minute, piston speed, is too much. This applies particularly to those pumps having short strokes. It has been found that trying to run such pumps at that speed has resulted in pounding and in unsatisfactory work. Therefore, in selecting a pump, particularly one with short stroke, it is best to select one having a capacity sufficient to deliver the requisite amount of water, when running at a very moderate speed, say 25 to 40 strokes per minute.

The water cylinder for some purposes is lined with a drawn brass tube forced into the bored cylinder casting. Holes for valve seats are bored, either with a straight taper of about an inch to the foot, or a taper tap is used, the valve seat being screwed in. A removable lining is sometimes used, made of gun metal, and this is so arranged that it can be turned in case one side gets worn.

The valves for water ends of pumps include clack or

flap, disc, ball, the wing or direct-lift valve and double-beat valves.

The clack valve is a piece of leather held by a metal plate with a metal plate under it to stiffen it. The object of the plate is to prevent the pressure forcing the leather through the valve seat. The leather forms a hinge. The disc valves are made of sheet metal or India-rubber composition. The ingredients of the composition are such as promote its capacity for wear or, in case hot water is to be pumped, for resisting heat. The composition which is combined with the rubber is said to be mostly oxide of zinc with a small percentage of sulphur.

The action of these valves is as follows: They move vertically up and down, the upward movement being induced by the pressure of the water and the downward movement by springs which are held by washers covering the ends of the springs. The valve stems pass through the center of the washers, springs and valve disc, and a nut on the end above the washer holds them in place. The valve seat is made of brass screwed into the partition between chambers. This takes the form of a circular grate.

INSIDE AND OUTSIDE PACKED PLUNGERS.

An inside packed plunger is one in which soft packing, hemp or other fibrous packing, is placed between the two end discs and forced out so as to make a tight joint with the cylinder walls. The outside plunger can leak only around the stuffing box and if this leaks it can be easily packed or the gland tightened.

Water pistons are sometimes made of brass. When packing a water piston the packing should be cut shorter than the outside circumference of the piston because, when it becomes wet, it will swell and greatly increase the friction if it does not stop the movement of the pump entirely. The inside plunger is beveled for gritty water.

DIMENSIONS OF A PUMP.

A pump is described by the diameter of its steam cylinder, the diameter of its water cylinder and the length of stroke. For instance, a $4'' \times 3'' \times 4\frac{1}{2}''$ pump has a steam cylinder 4 inches in diameter, a water cylinder 3 inches in diameter, and a length of stroke of $4\frac{1}{2}$ inches.

CALCULATIONS.

The height of suction, theoretically, can be no more than 34 feet under normal conditions. Actually, a pump can rarely lift through more than 30 feet and usually less. The temperature of the fluid pumped has a direct bearing on the suction height.

The diameter in inches of the water connections to the pump may be calculated as follows:

Divide gallons per minute by velocity of flow in feet per minute (200 feet for suction and 500 feet for discharge in feed pumps), extract the square root and multiply by 4.95.

To find the water H.P. required: *Multiply the equivalent of the pressure against which the pump is to work in feet head by the number of pounds of water pumped per minute. This gives the duty in foot-pounds. Divide the duty by 33,000 to get horse-power.*

To convert pounds pressure into feet head: *Multiply by 2.31.*

To convert gallons into pounds of water: *Multiply by 8.3356.*

To convert cubic feet of water into pounds: *Multiply by 62.5.*

To find the height of a column of water in feet, the pressure being given: *Multiply the pressure shown on the gage by 2.309; or the pressure by 0.434.*

To find the pressure of a column of water: *Multiply the height of the column in feet by 0.434. The product will be the pressure in pounds per square inch.*

One foot in height of the column is equal (approximately) to $\frac{1}{2}$ pound pressure per square inch.

To find the diameter of water cylinder necessary to deliver a certain number of gallons per minute, — the length of stroke and number of strokes per minute being given. *Multiply the number of gallons by 231. Divide the product thus obtained by the stroke of the piston. Divide this quotient by the number of strokes per minute. Then divide this quotient by 0.7854 and extract the square root. This will be the required diameter.*

Example: Required the diameter of the water piston necessary to deliver 51 gallons per minute, stroke of piston 12 inches, and speed 50 strokes per minute.

$\frac{51 \times 231}{12} \div 50 = 981.75 = 19.635.$ $19.635 \div 0.7854 = 25$ square inches.
The square root of 25 = 5, the required diameter of piston.

To find the capacity of a pump cylinder: *Square the diameter and multiply by 0.7854, and then by the length in inches, and divide by 231. For a given number of strokes per minute, multiply by the number of strokes.*

Example: Water cylinder diameter 4 inches, length of stroke 10 inches; find the capacity of the pump.

$$4 \times 4 \times 0.7854 = 12.56. \quad 12.56 \times 10 = 125.6.$$
$$125.6 \div 231 = 0.54 \text{ gallon per stroke.}$$

Example: To find the capacity of a pump in gallons at 100 feet piston speed, cylinder 5 inches in diameter. Square the diameter of the water cylinder and divide by 4. $5 \times 5 = 25$. $25 \times 4 = 100$ gallons per minute at 100 feet piston speed per minute.

To find the horse power of a pump necessary to feed a boiler evaporating a given number of pounds of water per hour and carrying a given steam pressure. *Multiply the pressure in pounds per square inch, against which the pump is operating, by the velocity of the flow of water in feet per minute. Then divide this product by 33,000 to obtain the required horse power.*

To determine the proper size of a pump to feed a boiler, the first step is to determine the probable amount of coal burned per hour and the probable evaporation of the water per pound of coal.

Suppose that each of two boilers has 19 square feet of grate surface and burns 10 pounds of coal per square foot of grate surface per hour and each pound of coal evaporates 8 pounds of water. Then the total evaporation equals $19 \times 10 \times 8 = 1520$ pounds per hour. $1520 \div 60 = 25.3$ pounds of water evaporated per minute for each boiler or 50.6 for both. $50.6 \div 8\frac{1}{3} = 6.8$ gallons per minute. To provide for all contingencies, the pump should have at least double this capacity, or be one that would deliver 13.6 gallons per minute when working at a moderate speed.

INJECTORS.

As it is necessary for the cold water supplied by the pump to be heated on its way to the boiler, this is usually done by the use of exhaust steam in a feed-water heater, the exhaust being supplied from the engines operating the plant. Then, if no engines are running, no steam, of course, will be available for this purpose. In this case, the injector may be employed. The principle

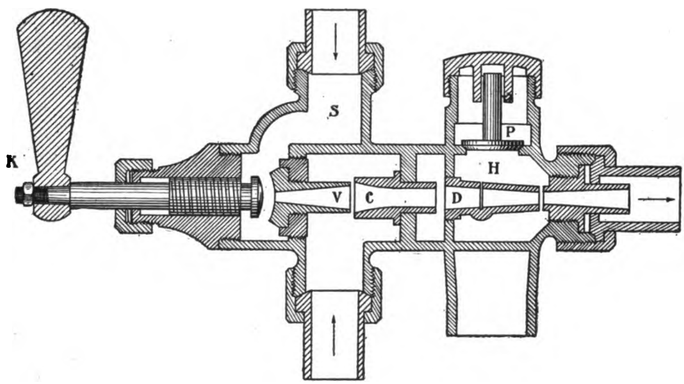


Fig. 61.

upon which the injector works is briefly as follows: A pipe connection, S, Fig. 61, to the upper part of the steam space is made, and the continuation of this pipe into the injector proper forms a steam nozzle, *V*.

The end of this nozzle extends almost into the second nozzle, C, called the combining or suction nozzle; this connects with, or rather terminates in, a third nozzle or tube, D, termed the "forcer." At the end of the combining tube, and before entering the forcer, is an opening

connecting the interior of the nozzle at this point with the surrounding area. This area is connected with the outside air by a check valve, P, opening outward in automatic injectors, and termed the overflow valve.

The operation of the injector is based on the fact, first demonstrated by Giffard, that the motion imparted by a jet of steam to a surrounding column of water is sufficient to force it into the boiler from which the steam was taken and back into the boiler working at a high pressure. The steam escaping from under pressure has, in fact, a much higher velocity than water would have under the same pressure and conditions. The rate of speed at which steam — taking it at an average boiler pressure of sixty pounds — travels when discharged into the atmosphere, is about 1700 feet per second. When discharged with the full velocity developed by the boiler pressure through a pipe, say an inch in diameter, the steam encounters the water in the combining chamber. Uniting with the body of water in the combining tube, it imparts to it a large share of its speed, and the body of water thus set in motion, operating against a comparatively small area of boiler pressure, is able to overcome it and pass into the boiler. The weight of the water to which steam imparts its velocity gives it a momentum that is greater in the small area through which its force is exerted than is the boiler pressure, although its force has actually been derived from the boiler pressure itself.

An injector is a very efficient substitute for a feed pump; but even though it puts the water into the boiler at 150° F., this high temperature does not represent a

coal saving because the heating is done by steam taken from the boiler itself, rather than by the waste heat of the exhaust steam.

Injectors should be used only as supplementary feed systems, or for portable boilers.

In round numbers it may be stated that for every 10° F. that the feed water is heated before entering the boilers, 1 per cent less coal is required to generate the same horse power. Also, for each 10° F. increase in feed temperature, the boiler capacity is increased 1 per cent. By transferring the exhaust of the feed pumps and other auxiliaries from the main condenser to the heater, the effective condenser capacity is increased 1 per cent for every 10° temperature rise of the feed. By feeding very hot water to the boilers the severe temperature strains that are the source of leaking tubes and seams are avoided.

In the injector, Fig. 61, the steam enters from above, the flow being regulated by the handle, K. The steam passes through the tube, S, and expands in the tube, V, where it meets the water coming from the suction pipe. The condensation takes place in the tubes, V and C, and a jet of water is delivered through the forcer tube, D, to the boiler. Connection passages are made to the chamber surrounding the tubes, C, D, to the chamber, H. If the pressure in this surrounding chamber becomes greater than that of the atmosphere, the check valve P is lifted and the contents are discharged through the overflow. So long as the pressure in this chamber is atmospheric the check valve, P, remains closed, and all the contents must be discharged through the tube, D.

There are three distinct types of live-steam injectors, the "simple fixed nozzle," the "adjustable nozzle," and the "double nozzle."

The first has one steam and one water nozzle which are fixed in position but are so proportioned as to yield a good result. There is a steam pressure for every instrument of this type at which it will give a maximum delivery, greater than the maximum delivery for any other steam pressure either higher or lower.

The second type has but one set of nozzles, but they can be so adjusted relative to each other as to produce the best results throughout a long range of action; that is to say, it so adjusts itself that its maximum delivery continually increases with the increase of steam pressure.

FEED-WATER HEATERS.

Feed-water heaters are made in two general forms, known as open and closed heaters. They resemble, in principle, jet or surface condensers in so far that, in the one case, there is a mixture of cooling and condensed water; in the other, the water is heated by flowing over heated surfaces. One disadvantage of the open heater is that oil and grease from the exhaust steam become mixed with the feed water.

Enclosed heaters are such as shown in Fig. 62, where a metallic vessel of suitable size contains a number of tubes or coils connected to partitions, so placed in the ends of the main vessel that the entering feed water is caused to flow or circulate through them in its passage from one end of the vessel to the other.

In the illustration, the exhaust steam is allowed to

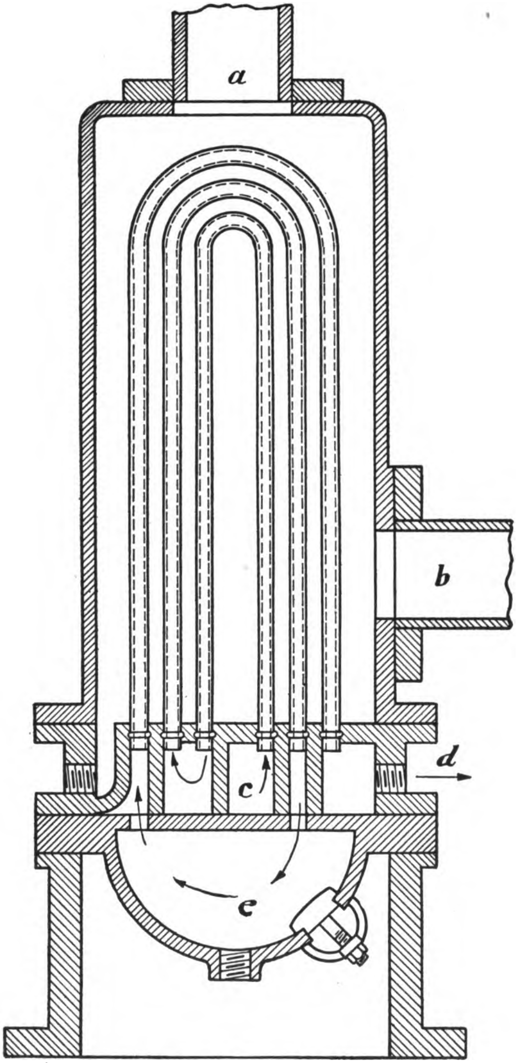


Fig. 62.

enter at *a* and fill the larger vessel, coming in contact with the surfaces of the pipes in such a manner as to thoroughly heat them and then passes out at *b*. This heat is absorbed by the circulating feed water which passes from the inlet *c* through the pipes, as shown by the arrows, and out at *d* to the boiler in a heated condition. The circulating pipes should preferably be made of brass or copper, and the points where they pierce the inner heads or plates should be carefully constructed and packed in order to remain perfectly tight and yet allow for expansion and contraction due to change in temperature. At *e* is a settling chamber to collect such solid material as may be liberated from the water. On both sides of each piece of apparatus, as feed-water heaters, pumps, injectors, etc., valves should be placed in order that the apparatus may be cut out of the line if necessary. On the feed line, a valve should be placed as close to the boiler as possible and just before this valve, usually of the ordinary globe type, a check valve must be used in order to prevent the pressure in the boiler from forcing the water out on the line again.

QUESTIONS.

1. What is a steam pump?
2. What forces water up into the suction pipe?
3. Which cylinder is the largest in steam pumps and why?
4. How much does a cubic foot of water weigh?
5. How many gallons are there in a cubic foot?
6. How much does a gallon of water weigh?
7. How many cubic inches in a U. S. Standard gallon?
8. Given the height of a gallon of water, how would you calculate its pressure per square inch?

9. How would you determine the height when the pressure is given?

10. How is the total resistance per square inch overcome by a water piston determined?

11. What difference does it make whether the supply is above or below the pump?

12. How would you calculate the pressure against which a pump will work?

13. How would you calculate the steam pressure necessary to operate a boiler feed pump?

14. How would you calculate the diameter of the water piston for a pump?

15. How would you calculate the diameter of the steam piston for a pump?

16. What is the limit of speed for a pump?

17. How would you calculate the capacity of a pump for 100 feet piston speed per minute?

18. How would you calculate the diameter of a pump piston to move a given quantity of water per minute?

19. How is the size of pipe, necessary to deliver a certain quantity of water, calculated?

20. What is the difference between the simple or single steam pump and the duplex pump?

21. How would you set the steam valves of a duplex pump?

22. When and why are steam valves given "lost motions"?

23. How many ports has a common duplex pump?

24. How many water valves has a duplex pump?

25. How high will a pump lift water?

26. Against what pressure will a pump work?

27. What can you say in regard to the pumping of hot water?

28. What is the purpose of an air chamber on a pump?

29. What is the effect of air in the suction pipe?

30. How would you find the horse power necessary to elevate water to a given height?

31. If a stand pipe is 100 feet high, what pressure will the gage show at the bottom?

32. What is a vacuum?

33. How many gallons per hour would be pumped by a pump having a plunger 6 inches in diameter, stroke 24 inches, speed 100 ft. per minute?

34. How many foot pounds work will be done if the water is pumped into a tank 50 feet above the supply?

35. How would you determine the efficiency of a pump?

36. What is an injector?

37. Why should both an injector and a pump be provided?

38. Describe a steam pump.

39. Describe a feed-water heater.

CHAPTER XVI.

CORLISS ENGINE.

One of the greatest advance steps in engineering work was the invention, by George Corliss, of the type of engine which bears his name.

The cylinder of the Corliss engine has four valves placed, as one might say, at the corners of the cylinder section. The two upper valves are the steam valves, the two lower are the exhaust valves.

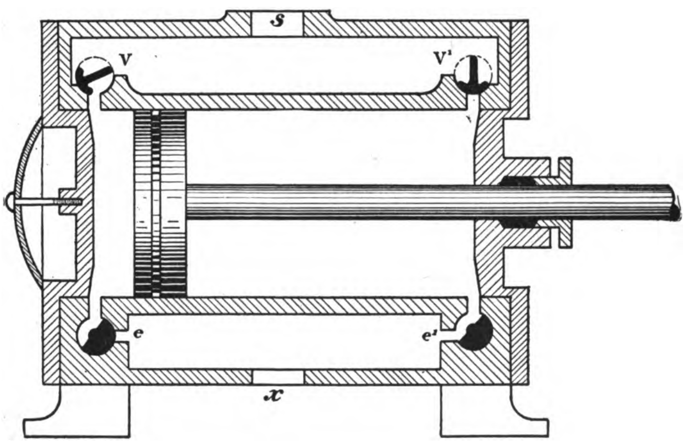


Fig. 63.

The seats on which they operate consist of openings bored through the cylinder casting at right angles to its length. The valves themselves are in the form of

cylinders, carefully fitted to these openings and having a portion of the central section removed as shown in Fig. 63. By reference to the figure it will be seen that steam entering through the main steam pipe *s* passes through a chamber close to the cylinder casting, thus helping to maintain the temperature of the cylinder, and enters the cylinder through one of the steam valves *v* or *v'*. After doing its work it passes out through one of the lower valves *e* or *e'*, passing through another chamber to the exhaust pipe *x*. The valves might be called oscillating valves, as they do not produce a complete revolution but swing on their centers to open and close the port openings. The ports, it will be noticed, are large, allowing rapid admission of the steam, and the valve being so near the cylinder proper there is very little length of port. Consequently, there is little energy lost due to a quantity of steam remaining in the ports, which enables close regulation. Referring to Fig. 64, illustrating the exterior view of the Corliss engine, it shows the reach rod *r*, which is operated by the eccentric through the eccentric rod and rocker arm. The reciprocating movement of this rod is employed to produce an oscillating movement of the wrist plate *w*, mounted on a stud at the side of the cylinder. This movement of the wrist plate produces a corresponding motion of the four studs *bb–b'b'* placed upon its face. This movement in turn is imparted by means of the adjustable rods *cccc* to the four valves. The lower studs *b'b'* are directly connected to the exhaust valves by means of the rods *cc* and the cranks *dd* keyed to the valve stems. The two upper studs operate the steam valves through

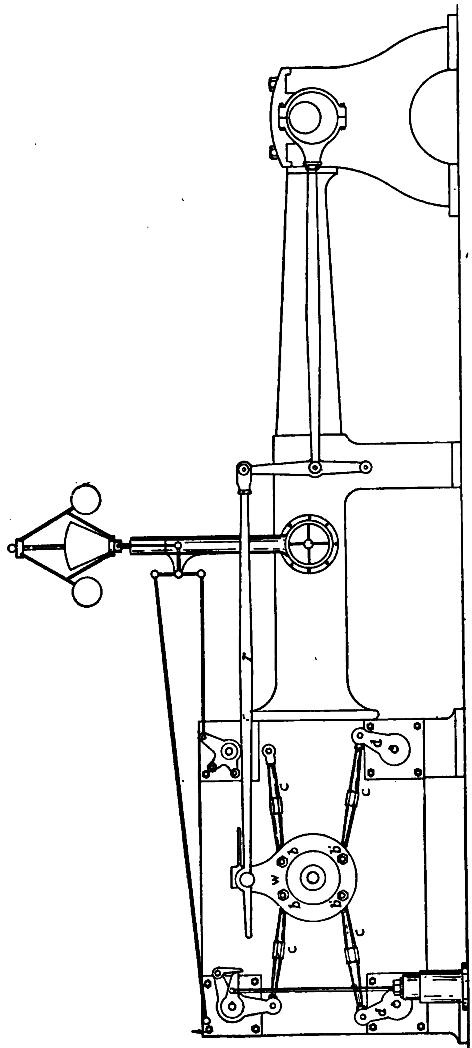


Fig. 64.

the valve mechanism or release motion as follows, see Fig. 65.

In admitting the steam the wrist-plate rod moves to the right and pulls with it the bell crank c', which has on one of its ends the hook e. In moving up, this hook engages with a pawl b fastened to the valve stem a, and lifts this pawl, rotating the valve on its center and allowing the admission of steam. The hook is pivoted as shown at d and carries a roller r fastened to a short arm on the reverse side of the supporting bell crank. The governor rod connected at 2 extends to a suitable crank on the engine governor and as the engine increases or decreases in speed the governor causes this rod to move j to the right or to the left. In doing so it turns the crank j upon its center causing the little roller on the opposite arm of the crank j' to vary its position on the circumference of a circle, having a as a center. At some point in the movement of the valve the roller controlling the hook e will come in contact with the roller on the bell crank j' connected to the governor rod. When this occurs the hook e is forced out, thus releasing the pawl on the valve stem.

The point at which these two rollers come in contact being regulated by the governor, the release of the valve occurs at an earlier or later period of the stroke as may be required by the work then being done. On the valve being released in this manner, it is free to close. In order to enable rapid closing there is pivoted to the pawl a vertical rod extending downward to the dash-pot. This may be placed in either a vertical or an inclined position, although the principle is the same in all. One

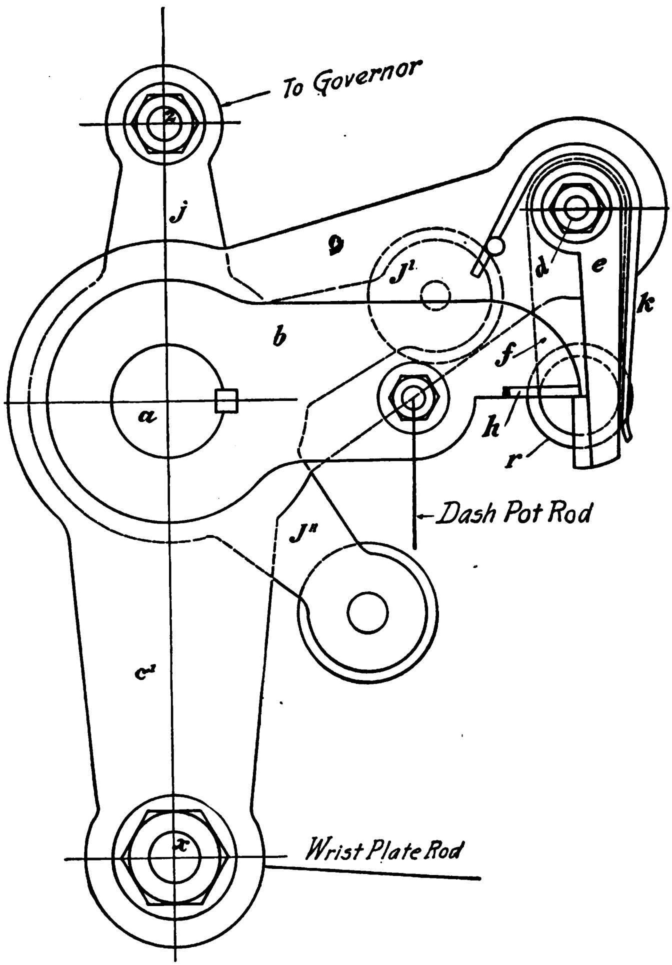


Fig. 65.

form is shown in Fig. 66 which consists of a stationary base *a* which is fixed to the engine frame, and a movable plunger *b* connected by the vertical rod *r* to the valve pawl. The plunger is fitted with packing rings, in order to produce an air-tight joint. When the hook is opening the valve, the rod is lifted, drawing the plunger upwards. An annular space is thus left below the plunger in which a partial vacuum is formed.

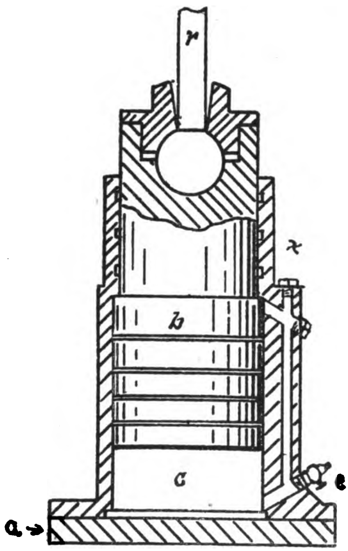


Fig. 66.

As soon as the valve has been released by the hook the atmospheric pressure on top of the piston pushes it rapidly downward, due to the partial vacuum below it. By means of the pull thus exerted on the rod it closes the steam valve almost instantaneously. The very small amount of air remaining in the dash-pot cylinder serves to cushion the plunger and prevent it from striking the bottom of the cylinder. Should too much air accumulate in here it may be allowed to escape by means of the check valve *e*.

COMPOUND ENGINES.

As we have already seen, economy is obtained by the use of high-pressure steam used expansively. On this principle it would be to our further advantage to increase our boiler pressure to 150 pounds or more per square inch, and produce a sufficient number of expansions to bring the back pressure considerably below that of the atmosphere. This would involve a large number of expansions, and consequently an extremely long engine cylinder. The difficulty in the way of employing such a cylinder is, in the first place, in the machining. Such a cylinder would be greatly distorted, largely due to the fact that, in the period of time elapsing while the piston was traveling from one end of the cylinder to the other, and due to the increased volume with consequently lowered pressure, the variation in temperature would be so great as to produce considerable condensation of steam. In order, then, to obtain good results without consequent ill effects, compound engines are used. These consist briefly of engines having two or more cylinders, acting on and delivering their power to the same crank shaft.

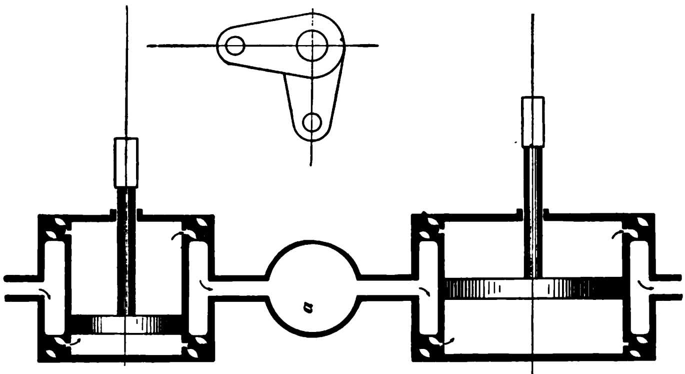
If, for example, steam at 150 pounds per square inch, occupying a volume of 2.96 cubic feet, were admitted to an engine and were allowed to perform its work and expand until it had reached the pressure of 75 pounds per square inch, this work would have been done under favorable conditions; but instead of allowing steam to exhaust from this cylinder at a pressure still sufficient to do good work and to escape to the atmosphere and thereby be lost, in the compound engine we now send

it into the cylinder of a second engine, so that the terminal pressure of steam of the first engine becomes the initial pressure steam of the second engine.

On account of its reduced pressure its volume would have increased to 5.68 cubic feet; therefore, the cylinder of the second engine should be proportionally larger in volume, so that at each stroke it might accommodate the steam exhausted from the first engine during each stroke. If, now, the connecting rod of both of these engines is connected to the same shaft, we will have the advantage of the high-pressure steam, the great number of expansions and the combination of the total power of the engines delivered to one shaft. This, in brief, is the compound engine. It may consist of two or more cylinders known respectively as double, triple, quadruple expansion, etc. The cylinder getting the steam first is called the high-pressure cylinder. That receiving it last is called the low-pressure cylinder. Where three or more cylinders are employed the others are called first and second intermediates, as the case may be. Compound engines are also designated according to their construction. When the cylinders are placed one behind the other, the piston being on the same piston-rod and having but one connecting rod and crank, it is called a tandem compound, Fig. 67, the path of the steam being indicated by the arrows.

If the engines are placed side by side having separate connecting rods and cranks they are called cross compounds, Fig. 68. While the latter type occupies considerable space it has the advantage in the fact that the cranks may be placed at right angles to each other,

thereby insuring ease in starting, for while one engine may be on the dead center the other will be at its point of maximum turning power. Also, if desired, one engine



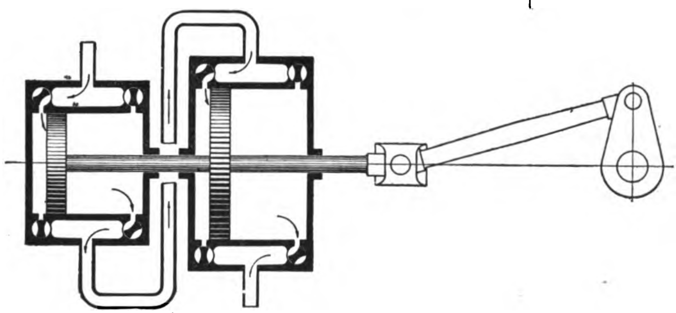


Fig. 67. Fig. 68.

may readily be disconnected from the shaft and the other one operated by itself.

These engines are sometimes built vertically and sometimes a combination of both the vertical and the horizontal type is employed in the same engine. When the steam passes from the high to the low pressure

cylinder it is occasionally led to a receiver connected between two engines in which it may be slightly superheated before entering the second cylinder. This is done in order to get rid of any moisture which may have collected Fig. 68, *a*.

In all cases the length of stroke of the pistons are alike; therefore, the increase in volume is gained by increasing the diameter of the lower pressure cylinders. In considering the use of high-pressure steam in connection with compound engines, it is necessary to determine how many expansions we desire to obtain. If, for example, the steam pressure be limited to 185 pounds absolute and the terminal pressure be considered as 6 pounds absolute, we apply the following rule:

Divide the absolute initial steam pressure by the absolute terminal pressure and the quotient will be the total number of expansions. Thus we have $\frac{185}{6}$ which equals 30.8 expansions. As there will be a slight loss between the cylinders this will produce actually about 30 expansions.

Having determined the total number of expansions, in order to find the approximate number in each cylinder we employ the following rule:

For double expansion, extract the square root of the total. For triple expansion, extract the cube root of the total. For quadruple expansion extract the fourth root of the total. Therefore in a triple expansion engine having 30 expansions the approximate number obtained in each cylinder would be $\sqrt[3]{30} = 3.1$.

It is customary and preferable in actual operation

to make the cut-off in the high-pressure cylinder a little earlier than in the others. This will ordinarily produce the following results:

Total 30	high pressure	3.2 expansions
	intermediate..................	3.1 "
	low pressure..................	3.0 "

In the case of compound engines the condenser is of special value, enabling us to obtain the greatest number of expansions by bringing the terminal pressure below that of the atmosphere.

CONDENSERS.

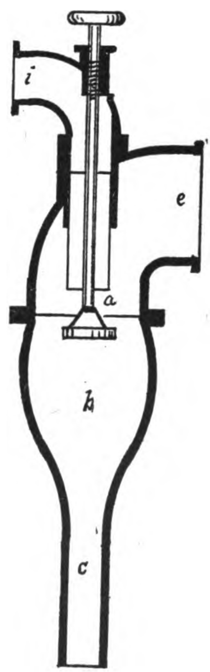


Fig. 69.

There are many styles of condensing apparatus, but they may be placed as belonging to two types known as first, jet condensing, and second, surface condensing apparatus. In either case quantities of water are required to produce the cooling action necessary; therefore, particularly in cities, unless large quantities of water can be obtained from artesian wells or similar sources, condensing is not resorted to unless in a plant of fairly large size which will run economically even with the extra expense of the water and incidental apparatus. The jet condensing apparatus, Fig. 69, consists of a vertical hollow vessel *b*,

one end connecting with the cylinder by the exhaust pipe *e* and the lower end with the air pump at *c*, the whole system being perfectly air-tight. Into the condenser and near the inlet for exhaust steam is introduced a spray pipe or sprinkler *a* by means of which a shower of cold water entering at *i* is allowed to mingle with the exhaust steam, condensing it and producing a

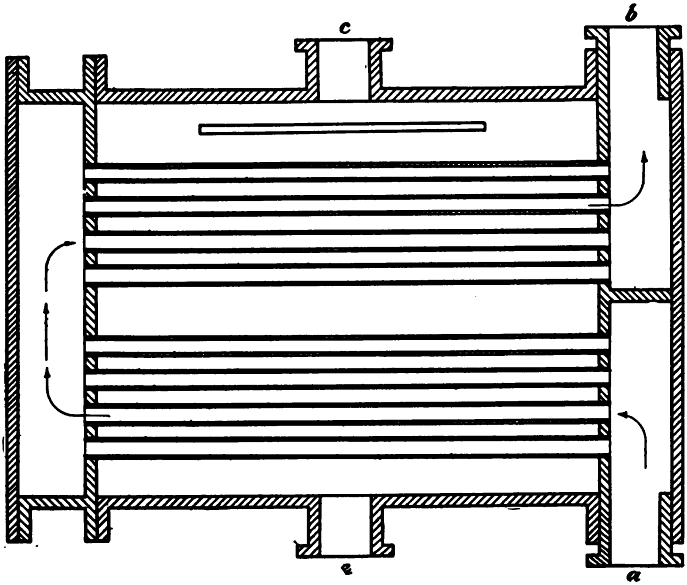


Fig. 70.

mixture of injection water and condensed steam which falls to the lower portion of the condenser and is pumped out of it to the hot well. The surface condenser does not mix the water and exhaust steam. A series of tubes are placed in the main body of the condenser,

through which a quantity of cold water is maintained in circulation. The exhaust steam entering the body of the condenser, surrounding and coming into contact with the cool surfaces of the pipes containing the circulation water, is condensed and disposed of as in the previous case.

In Fig. 70 is shown a surface condenser. The cooling water entering at *a* passes through the tubes as shown by the arrows, and out at *b*. The exhaust steam enters at *c*, the water of condensation being pumped out at *e*.

QUESTIONS.

1. Describe briefly a Corliss engine.
2. Wherein does it differ from the ordinary slide-valve engine?
3. Describe the valve motion?
4. What is the object of the dash-pots?
5. What is a compound engine?
6. Name some advantages due to its use?
7. Why do the cylinders differ in size?
8. How are the total number of expansions determined?
9. What is a condenser?
10. Describe a surface condenser; a jet condenser.

CHAPTER XVII.

PIPES AND FITTINGS.

In order to connect the boilers, engines, pumps, and various other pieces of apparatus so that steam and water may flow between them, hollow iron conductors called *pipes* are employed.

The pipes are joined by the use of small properly shaped pieces, suitably threaded, called "fittings."

Pipes are either welded or riveted, according to their size. Steam piping is spoken of in terms of the inside diameter or size of the opening. For example: A half-inch pipe implies that the inner diameter is approximately one half inch. The outer diameter would probably be nearly three quarters of an inch. Similarly, a one-inch pipe would have an exterior diameter larger than one inch, while the opening would be approximately one inch in diameter.

Tubing, however, under which head would be placed brass pipe and boiler tubes, is measured by its outside diameter.

Pipe is supplied in lengths having a thread at each end. Pipe threads, as well as the threads in all fittings, where such are required, unless otherwise specified, are supplied as right-hand threads. This means that in turning a right-hand screw or thread, in order to tighten it, it will be turned in the same direction as that taken by the hands of a clock; and in the reverse direc-

tion in order to loosen it. Conditions sometimes require the use of a thread working in the opposite direction. When this is the case a left-hand thread must be specified.

When connecting two pieces of pipe, one being a continuation of the other, a short piece of pipe, threaded internally to fit the external threads on the pipe ends, is used. This fitting, as shown in section, No. 1, Fig. 71, is called a *coupling*. The threads on the ends of steam pipes are made tapering; that is, the front end is smaller in diameter than the rear end. Threads in fittings are tapered in a similar manner. This makes it easier to screw together at the start and the further they are turned the tighter the threads get, finally wedging together as a steam-tight joint, which would, of course, be impossible were the threads parallel in diameter as is the case in an ordinary machine screw.

It is sometimes required that the ends of two pipes already in position be connected as in the previous case, so that screwing the coupling up on one pipe would unscrew it from the other, in case all right-hand threads are used. In such a case, the external thread on one pipe end is made left-handed and the other right-handed and a similarly threaded *right and left coupling* is employed. On account of the difference of angle in the threads both will tighten up or loosen at the same time. The external appearance of this coupling differs from the previous one in having several straight, raised projections, lengthwise of itself.

When necessary to join two pipes at right angles with each other a fitting called an *elbow* or *ell* is used, No. 2,

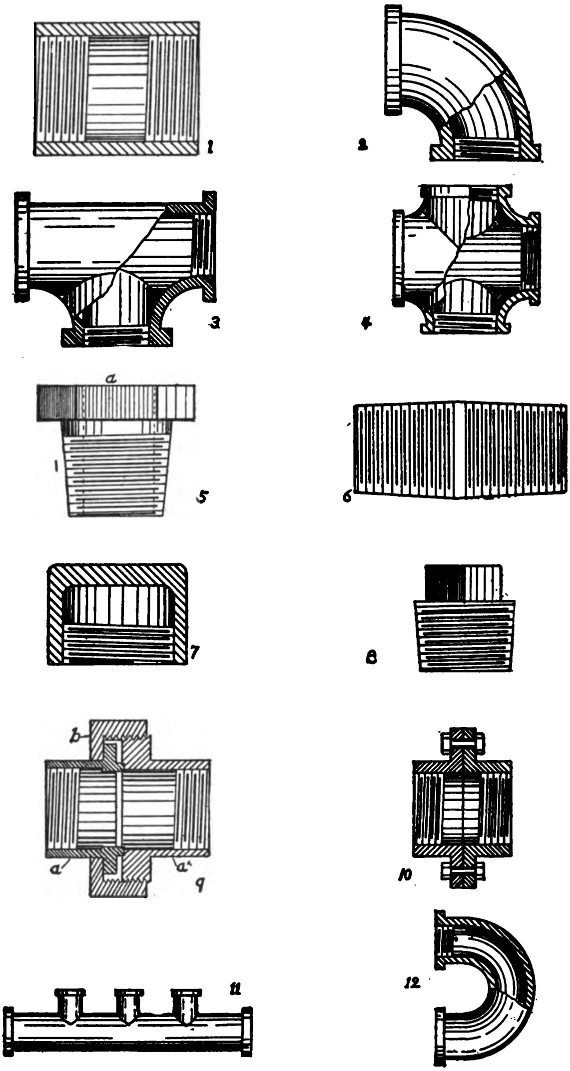


Fig. 71.

Fig. 71. Unless otherwise specified, these elbows are supplied with openings at 90° to each other. They may, however, be obtained with openings at other angles to each other as well as with an additional opening on the side of the elbow, if so desired.

Where a line of pipe is joined in some part of its length by another pipe at right angles to it, the joint is formed by a fitting called a *tee,* No. 3.

Where two lines of pipe cross each other, forming four right angles, a fitting called a *cross* is employed, No. 4.

If it is desired to join two pipes of different diameters with one fitting it is done by the use of a fitting having openings of the required diameters for the two sizes of pipe and this is called a *reducing coupling, or elbow,* as the case may be.

If it is desired to screw a pipe into a larger fitting the space between the two may be filled by the use of a *bushing* as shown in No. 5. This is a piece of material having an internal thread to fit the smaller and an external thread to fit the larger size with a hexagonal shape at *a*, to fit a wrench, for convenience in tightening.

If two fittings or valves are placed close together and only a short piece of pipe is required to join the two, this pipe is called a *nipple,* No. 6. If this is so short that the threads meet, as shown in No. 6, it is called a *close nipple.* If there is, perhaps, half an inch of blank space between the threads, it is called a *short nipple,* and one somewhat longer, extending to two or three inches in total length, would be called a *long nipple.*

If it is desired to close the end of a pipe, the *cap,*

No. 7, is used; or to close the opening in a fitting, the *plug,* No. 8, will serve.

Sometimes the right and left coupling may not be convenient to join pipes, under the conditions previously mentioned. For this purpose we will employ a fitting called a *union,* No. 9. It consists of three pieces, two of which, *a* and *a′*, are threaded internally with right-hand threads. These screw on the ends of the pipes to be joined together. The loose collar *b* slides over the portion *a* of the union and is stopped by the projecting rim. It is then screwed on to *a′*; the tighter it is screwed in position the closer the two portions of the union, *a* and *a′*, are drawn together.

In the case of the common union, opposing surfaces of *a* and *a′* are separated by a washer, made of packing, in order to enable a tight joint to be formed. In the better grade of unions this is a ground joint, the face in contact being turned to a hemispherical form and then carefully ground to a tight fit. No washer is required in this case.

In joining the ends of large pipes together, or to valves, the flanged coupling, No. 10, is largely used. It consists of a disc threaded internally to receive the pipe and having on the flat portion several holes to receive the bolts. These are used in drawing the faces of the flange firmly together. The space between the faces is filled either with sheet packing, copper or other suitable material. Occasionally the inner edge of the thread is chamfered off, and the pipe having been screwed home is peened over, after which the entire flange and pipe is machined absolutely true in order to make a first-class joint.

In steam heating the radiators are sometimes made of a number of pipes, parallel with each other and screwing into one casting at the end. Such a fitting is called a *header,* No. 11. Again the radiator will sometimes consist of pipes parallel to each other, connected from one to the other in zig-zag fashion, the fitting in this case being called *return bends,* No. 12. These fittings and valves are not, by any means, all of those employed in steam-fitting work, but they comprise the principal ones in ordinary use. Other fittings employed will be needed only in special cases and to meet extra conditions, and even then they will vary in shape, but not in principle, from those illustrated.

VALVES.

In order to control the flow of a liquid through pipes, valves are employed. These are really nothing more nor less than suitably constructed fittings of various kinds so arranged that they may be operated either automatically or by hand.

In Fig. 72, showing a globe valve which is representative of a large number of valves used in an engine plant, the main casting, spherical in shape, gives it its name, the globe valve.

At *a* is a circular plate or disc, the lower surface being either flat or beveled and of metal or other suitable material, and forming the actual door which is opened or closed. *c* is a ring which forms the seat of the valve. The surfaces of *a* and *c*, which come in contact, are accurately fitted in order that they may be steam-tight when closed. The rod, *b*, is the stem of the valve.

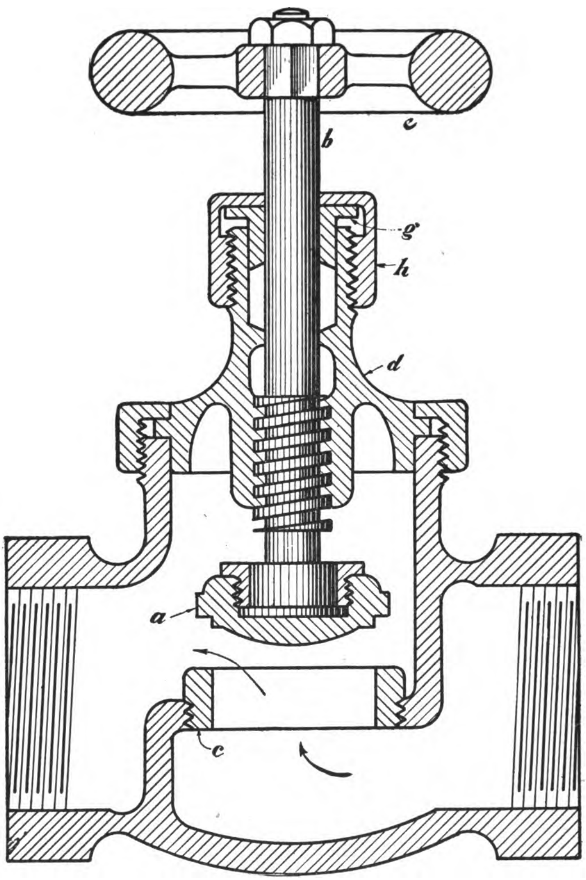


Fig. 72.

The lower end is so fitted into the projection on the upper part of the disc that it is free to revolve in the disc and yet carry the disc with it. On the stem is shown a thread which screws into the nut, *d*. This enables the

valve to be opened or closed by turning the stem by means of the hand-wheel, *e*. In order to prevent leakage through the threaded portion of the stem, the stuffing box is provided, as shown. This consists of a recess made in the projecting hub which is filled with asbestos wicking. The gland, *g*, is pressed down upon the asbestos by means of the nut, *h*. This forces the packing snugly around the valve stem and prevents any leaks. The ends of the body are shown threaded to fit the steam pipe.

In its passage through this valve, as indicated by the arrows, the steam must make two right-angle bends which, of course, produce considerable friction.

These valves are sometimes made with the threaded portion of the pipe at right angles to each other. They are then called angle valves, but the same principle of construction holds good in all cases.

In the larger forms, with slightly different details of construction, they are used as the main valves on engines and boilers, in which case they are called stop valves.

In the large sizes, instead of being threaded to receive a pipe, they are supplied with flanges, by means of which they may be bolted into position.

Mention has been made of the fact that the course of the steam through this valve is rather indirect. This would become a serious objection were the heavier fluids, such as water, employed. To overcome this difficulty, valves on water lines are often of the straight way or gate valve type. Such a valve has the seat and disc, as before, with the exception that they are placed in a vertical position.

The disc proper is somewhat wedge shaped. The seat is composed of two parts, *a* and *b*, Fig. 73, the front portion *a* being the seat proper, as before, and when the

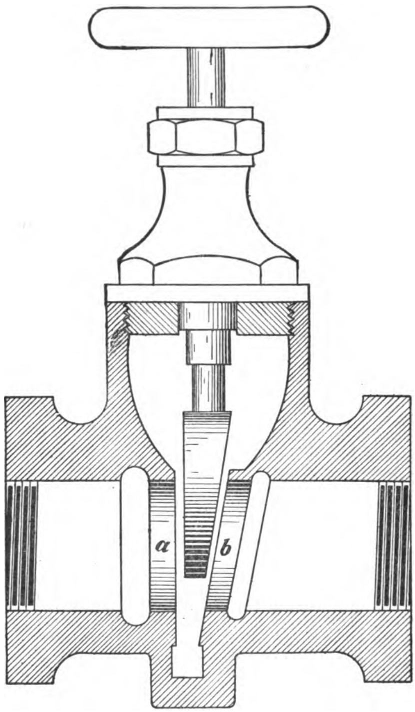


Fig. 73.

valve closes, the rear portion *b*, an inclined surface on which the disc slides, forces the valve disc tightly against the seat *a* as the disc is lowered by means of the valve stem connected in similar manner to that of the globe valve. This construction is shown in Fig. 73,

which also makes it clear that the passage of the liquids through this valve will be in a continuous straight line.

Another valve largely used for certain purposes in the engine and boiler room is of the plug type, as shown in Fig. 74. This is similar in construction to the valve

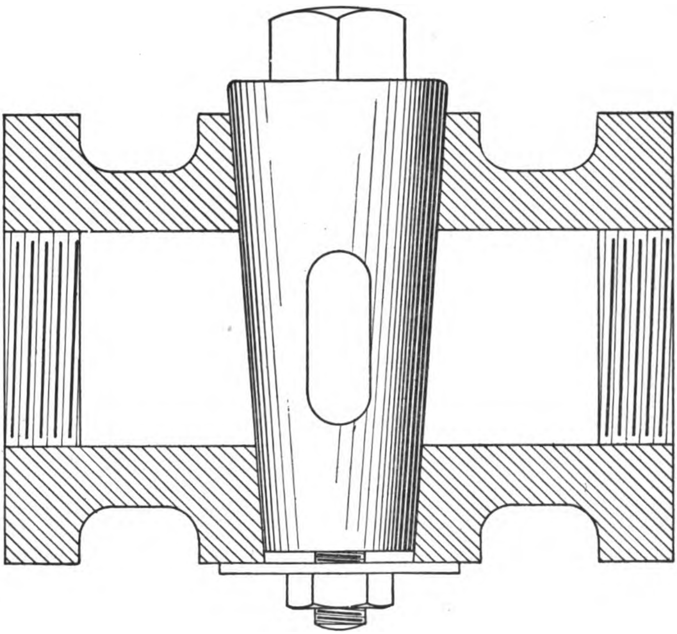


Fig. 74.

used on the ordinary gas jet, consisting of a body in which is made a tapered hole.

A tapered plug is fitted into the hole, both being carefully ground together. The nut and screw on the

plug enable us to draw the plug farther in the hole and tighten the valve, in case of a tendency to leak.

A combination to some extent of the plug and globe valves, carefully packed under heavy pressure, is used for boiler blow-off valves. These are made unusually strong because, due to the position in which they are placed, they cannot so readily be observed. Their work is extremely important for, should a serious leak occur, they will possibly allow the water to flow out of the boiler when in operation, thus producing serious results.

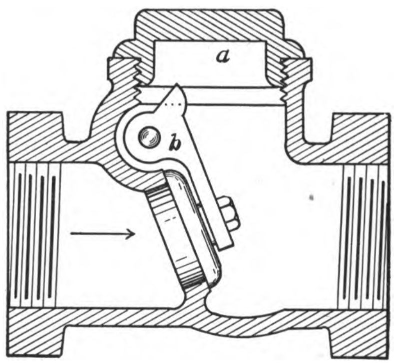


Fig. 75.

Another very important and largely used valve around the steam plant is known as the check valve. This is an automatic valve, in the sense that it will take care of its own operation. It is designed to allow the flow of liquids or gas only in one direction.

Figs. 75, 76, and 77 illustrate three types of check valves. In Fig. 75 is illustrated a swinging check valve. The body is similar in construction to that previously shown, except that there is no stem present and the

valve disc rests upon a seat placed at an angle in the valve body. The disc swings by means of the arm *b* from the pivot. Liquid, passing in the direction of the

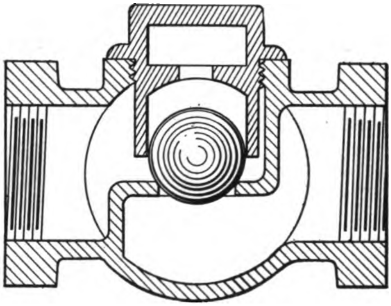


Fig. 76.

arrow, will lift the disc, and pass on. Any attempt to flow in the opposite direction will close the valve, and

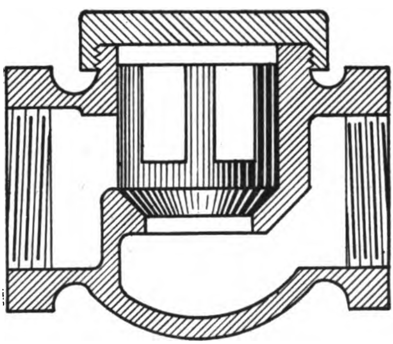


Fig. 77.

the greater the pressure, the more tightly the valve will be closed. The cap, shown at *a*, is necessary for placing in position the disc and the arm.

In Fig. 76 is shown a ball check valve. The ball seen resting on its seat is lifted by the pressure below it into the recess above, allowing the flow of liquid in one direction. The pressure produced in the other direction forces the ball down to its seat, thus closing the valve.

In Fig. 77 a similar valve is shown, the only difference being that, instead of a ball, the disc is used as before. This is guided in the recess by the wings or vanes, shown above it. The method of operation is similar to that previously described.

Sometimes steam is desired at a lower pressure than that in the boiler. Suppose, for example, the boiler is supplying steam at 80 pounds to run the engine, and steam at 8 or 10 pounds is desired for some heating apparatus. This must be taken from the boiler supplying steam at the higher pressure. This reduction is accomplished by throttling the steam with a reducing valve. These may be operated automatically and a constant pressure maintained in the steam pipe. In one instance, Fig. 78, a diaphragm of rubber material is placed at *a*, having its edges clamped by means of the bolts *b*, extending around its circumference. The center portion of the diaphragm is held by means of the nuts above and below, shown on the spindle or stem of the valve *v*. The steam pressure acts on the lower side of the diaphragm tending to lift and close the valve, while the weight set to produce the desired pressure tends to open it. The movement of the diaphragm, due to either of these causes, produces a shifting of the balanced valve *v*. When live steam is turned on, the

valve is full open. This is due to the pressure of the weight above. When the pressure passing through and acting on the diaphragm equals the weight above,

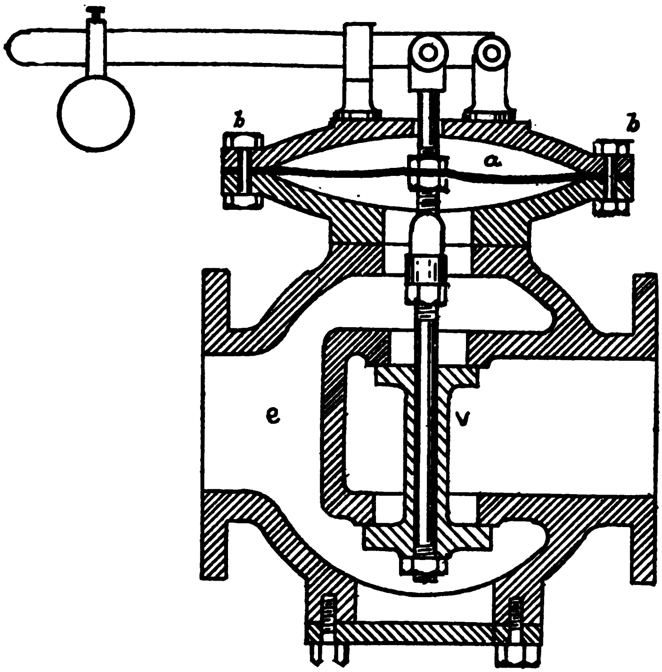


Fig. 78.

the tendency of the valve is to close. Therefore, this action maintains the valve open just sufficient to allow enough pressure per square inch to be maintained on the side *e* of the valve.

In all plants there is more or less loss, due to condensation. Particularly is this the case where long

lines of steam supply or steam-heating pipes are used. It is necessary to get rid of this entrained water of condensation as soon as possible, both in order to prevent annoyance and injury and also to prevent greater condensation taking place, due to the presence of the cooler water.

For this purpose steam traps are employed. The

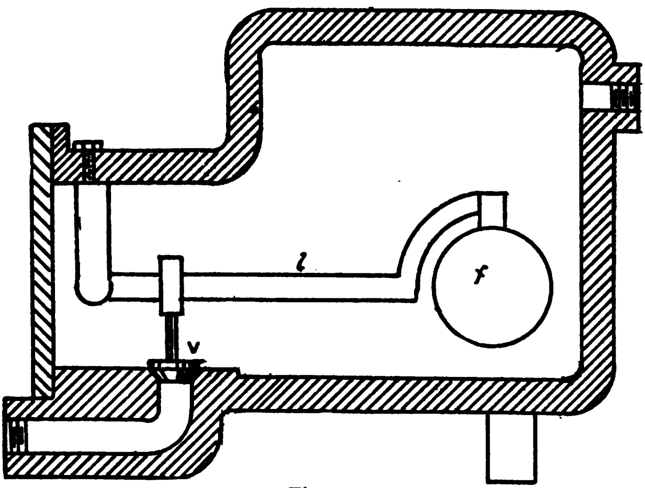


Fig. 79.

principle of construction is extremely simple. The object to be obtained is to rid the pipes of the condensed water without allowing the steam to escape. Such a trap, Fig. 79, consists essentially of a chamber connected to the steam pipes at such a point that any condensed water will readily flow into the main body of the trap and there be collected. Forming a portion of the trap is the valve *v*, which is normally closed, due to the

weight of the lever *l*, and the float *f*, pressing down upon it. The float may be a hollow metallic ball or receptacle of any suitable size or shape. As the water collects in the main body of the trap and finally reaches a height sufficient to lift the float, this action will open the valve, allowing water to flow out, nearly emptying the trap. As the steam is pressing on the upper surface of the water, and the lowering of the level of the water causes the float to drop and the valve to close before all of the water has passed out, there consequently is no chance for the steam to escape at any time, because it is trapped by the presence of the remaining body of water between itself and the opening, and the trap is never entirely drained while in use.

In the main steam pipe from the boiler to the engine it is also advisable to place a steam separator, because, even in a properly designed and installed steam plant, more or less moisture is carried over with the steam into the engine cylinder, and conditions may arise which will cause an increase in the amount of this moisture. Some means, therefore, should be taken to separate it from the steam in its passage to the engine. The principle of such a steam separator is shown in Fig. 80 where the steam, instead of being allowed to pass directly along the pipe, makes several changes in direction by striking the baffle plates *b*, placed in the main chamber of the separator. The steam at high speed readily changes its direction. The weight of the entrained water, however, and its momentum causes it to be carried in a straight line and strike the sides of the metallic plates to which it will cling in preference

to passing on with the steam. The water then runs down the plates and collects in the receiver at the bottom, whence it is drained by the steam trap.

Of somewhat similar design to the steam separator is the grease extractor or separator, employed where the

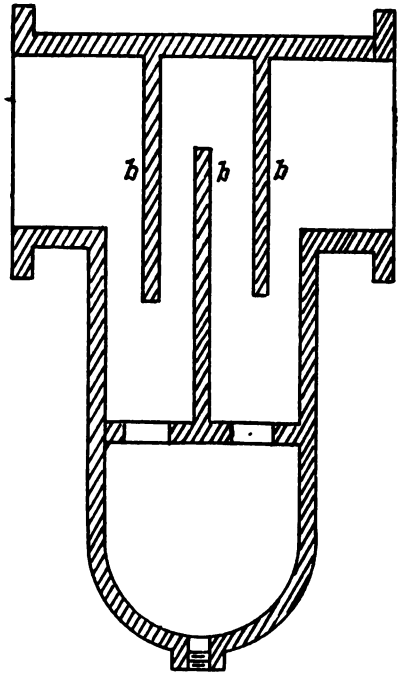


Fig. 80.

condensed water from the exhaust steam is to be used over again. It is necessary to cleanse this water of the cylinder oil and other grease, which it may have collected on its passage through the engine, and to do this it is allowed to pass into a large vessel, a portion of

which is occupied by either gratings or chains or similar objects suspended in the path to be taken by the exhaust steam. The contained oil and grease, to a very large extent, collects on the surface of these metallic bodies. The steam, in the form of condensed water, then passes to a supplementary purifying chamber and then being practically free from all grease and oils, collects in a reservoir from which it may be pumped for use.

EQUATION OF PIPES.

It is frequently desirable to know what number of one-sized pipes will be equal in capacity to a single given pipe for delivery of steam, air, or water. At the same velocity of flow, two pipes deliver as the square of their internal diameters; but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary as the square root of the fifth power of the diameters. The friction of a fluid within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is greater in proportion to the contents of a small pipe, than of a large one. In a given pipe it is equal, approximately, to a constant, multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter, by the diameter increased by a constant. Careful comparison of a large number of experiments by different investigators has developed the following as a close approximation to the relative flow in pipes of different sizes under similar conditions:

$$W \propto \frac{\sqrt{d^6}}{d + 3.6} \quad \text{or} \quad \frac{d^3}{\sqrt{d + 3.6}},$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

FLOW OF STEAM THROUGH PIPES.

The approximate weight of any fluid which will flow in one minute through any given pipe with a given head or pressure may be found by the following formula:

$$W = 87\sqrt{\frac{D(p_1 - p_2)d^5}{L\left(1 + \frac{3.6}{d}\right)}},$$

in which W = weight in pounds avoirdupois, d = diameter in inches, D = density or weight per cubic foot, p_1 = the initial pressure, p_2 = pressure at end of pipe and L = the length in feet.

The table on page 193 gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure, through straight smooth pipes, each having a length of 240 times its own diameter.

For sizes of pipe below 6 inches, the flow is calculated from the actual areas of "standard" pipe of nominal diameters.

For horse power multiply the figures in the table by 2. For any other loss of pressure multiply by the square root of the given loss. For any other length of pipe divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient, which will give the flow for 1 pound loss of pressure. Conversely, dividing the given length by 240 will give the loss of pressure for the flow given in the table.

FLOW OF STEAM THROUGH PIPES.

Initial gage pressure. Pounds per square inch.	Diameter in inches. Length 240 diameters.								
	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6
	Weight of steam per minute. 1 pound pressure loss.								
1	1.16	2.07	5.7	10.27	15.45	25.38	46.85	77.3	115.9
10	1.44	2.57	7.1	12.72	19.15	31.45	58.05	95.8	143.6
20	1.70	3.02	8.3	14.94	22.49	36.94	68.20	112.6	168.7
30	1.91	3.40	9.4	16.84	25.35	41.63	76.84	126.9	190.1
40	2.10	3.74	10.3	18.51	27.87	45.77	84.5	139.5	209.
50	2.27	4.04	11.2	20.01	30.13	49.48	91.34	150.8	226.
60	2.43	4.32	11.9	21.38	32.2	52.9	97.6	161.1	241.5
70	2.57	4.58	12.6	22.7	34.1	56.	103.4	170.7	255.8
80	2.71	4.82	13.3	23.8	35.87	58.9	108.7	179.5	269.
90	2.83	5.04	13.9	24.9	37.5	61.6	113.7	187.8	281.4
100	2.95	5.25	14.5	26.	39.1	64.2	118.5	195.6	203.1

The loss of head, due to getting up the velocity, to the friction of the steam entering the pipe, and passing elbows and valves will reduce the flow given in the tables. The resistances at the opening and at a globe valve are each about the same as that for a length of pipe equal to 114 diameters divided by a number represented by 1 + (3.6 ÷ diameter). For the sizes of pipes given in the table, these corresponding lengths are:

Diameter in inches	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6
Equivalent pipe, length in feet.....	20	25	34	41	47	52	60	66	71

The resistance at an elbow is equal to two-thirds of that of a globe valve. These equivalents — for open-

ings, for elbows, and for valves — must be added in each instance to the actual length of pipe. Thus a 4-inch pipe, 120 diameters (40 feet) long, with a globe valve and three elbows, would be equivalent to $120 + 60 + 60 + (3 \times 40) = 360$ diameters; and $360 \div 240 = 1\frac{1}{2}$. It would, therefore, have $1\frac{1}{2}$ pounds loss of pressure at the flow given in the table, or deliver $(1 \div \sqrt{1\frac{1}{2}} = 0.816)$ 81.6 per cent of the steam with the same (1 pound) loss of pressure.

FLOW OF STEAM FROM A GIVEN ORIFICE.

Steam of any pressure flowing through an opening into any other pressure, less than three-fifths of the initial pressure, has practically a constant velocity, 888 feet per second, or a little over ten miles per minute; hence the amount discharged in pounds is proportionate to the weight or density of the steam. To ascertain the pounds, avoirdupois, discharged per minute, multiply the area of opening in inches by 370 times the weight per cubic foot of the steam.

Or the quantity discharged per minute may be approximately found by Rankine's formula:

$$W = 6\,ap \div 7,$$

in which W = weight in pounds, a = area in square inches, and p = absolute pressure. The theoretical flow requires to be multiplied by a constant k = 0.93 for a short pipe, or 0.63 for a thin opening, as in a plate, or a safety valve.

Where the steam flows into a pressure more than two-thirds the pressure in the boiler,

$$W = 1.9\,ak\,\sqrt{(p - O)\,O},$$

in which O = difference in pressure between the two sides, in pounds per square inch, and a, p, and k are as above.

To reduce to horse power multiply by 2.

Where a given horse power is required to flow through a given opening, to determine the necessary difference in pressure:

$$O = \frac{p}{2} - \sqrt{\frac{p^2}{4} - \frac{(H.P.)^2}{14a^2k}}.$$

PACKING.

Where two parts of a boiler, engine, or other steam apparatus are to be joined and are exposed to steam pressure, it is necessary that they be made steam-tight. In some instances this may be done by very careful facing of the parts, having them perfectly clean and bolted together absolutely true to each other. In the majority of cases, however, it is necessary to interpose some other material between the two surfaces in order to make an absolutely tight joint. Possibly the simplest form of *packing* is that employed where two pipes of ordinary size are screwed together, the threads having been coated by the fitter with a quantity of red lead which serves to fill any small openings that may exist between the thread surfaces when brought in contact with each other. In some instances where flat surfaces of considerable size are in contact, such as flanged couplings, small cylinder heads, etc., the surfaces having been carefully machined, a washer or ring of strong paper inserted between the two is sufficient to produce the desired effect.

Whenever a ring of this character, of considerable size and flexible material, is used for this purpose in steam work, it is called a *gasket*. Instead of paper a gasket of corrugated copper is often used. The copper is soft and when the bolts are tightened, it forces the corrugations down and closes up all crevices. In case of extremely high pressure, a groove is turned in each of the opposing faces; in this is placed a wire of soft material, such as lead. For manholes in boilers, large cylinder heads, and in many cases for valve stems, piston-rods, etc., packing is made either in sheet form, to be cut as desired, or made to fit the stuffing box accurately. This may be of various materials, depending upon the conditions to which it is to be exposed. Textile packings are also largely used. These are made of flax or hemp, or, with these as a base, in combination with asbestos and rubber. These will not, however, serve for high-pressure packings except in combination with asbestos on account of its higher resistance to heat. It is necessary to keep asbestos as dry as possible, as moisture will readily disintegrate and destroy it. One method of overcoming this trouble is to mix in rubber or to give it a coating of graphite and grease. One method of making packing is by alternating layers of rubber and asbestos thread, braided around a suitable core. After thoroughly coating this with rubber, the operation is continued until the required size is obtained. Soapstone is sometimes employed to prevent moisture in asbestos packing; the principal objection to its use is that it is not a fibrous material. Metallic packings have been largely used, particularly on piston-

rods, in recent years. They are usually composed of babbitt or of similar anti-friction metals and are made in rings, so formed that when placed in the stuffing box and tightened they slip on and form closely around the piston-rod allowing it to move freely and yet prevent the passage of steam. In another case fibres or pellets of material are placed in small bags. These are coiled around the rod in position, the gland is screwed down, friction rapidly wears away the cloth covering and the material beds itself closely around the piston-rod. For hydraulic work packings are also made of rawhide and similar material not readily affected by water. When placing a packing in position, such as the gasket on an engine, it is necessary first to see that all metallic surfaces are carefully scraped clean, that all bolt holes are carefully and cleanly cut, and that a coat of hard grease and graphite is rubbed on each side of the gasket. It is then placed in position and the various nuts tightened evenly by drawing up a little at a time on each one. Never draw up one nut or bolt tightly, leaving the others entirely loose. In the case of the packing of a pump, or cylinder head of a gas engine or any machine where, in addition to bolt holes, openings must be left for passage of water or other liquids or gases, care must be taken to see that all of these are opened before attempting to put the gasket into position. For gas engines, where the packing is exposed to extra heat and high pressure, a packing composed of asbestos fibres in combination with a wire gauze is now largely used.

HEAT AND COLD INSULATORS.

Since to insulate means to separate, heat and cold insulators are obviously intended to separate such bodies. This is a matter of vital importance in the plant, not only for convenience but from considerations of economy. If fuel is purchased and burned with the idea of producing heat which is in turn to produce work, it is not good policy to allow this heat to escape before its work has been done.

For this reason it is necessary to cover all boilers, pipes, etc., that conduct steam, with such materials as will, to a considerable extent, prevent the condensing action due to the cooling effect of the atmosphere.

Pipe coverings, like other things in the engineering lines, are of many kinds and a detailed consideration of each is not necessary. It may be mentioned, however, that one of the principal methods of insulating pipes, in order to prevent condensation, is by covering them with an asbestos mixture. Asbestos is a rock of fibrous nature, found all over the world in various grades, the best for our purpose being obtained in Canada. It is readily separated into silky fibres. These are thoroughly mixed with a binding material, magnesia or other non-conductor of heat and placed upon the market in the form of sheets, bricks and tubes, and in pulverized form.

The bricks are largely used to cover upper portions of boilers exposed to the air. The tubes, called *pipe covering*, are placed over steam piping and held in position by a canvas coating pasted on the surface.

The pulverized material, mixed with water, forms an

adhesive plaster, readily applied to surfaces of any shape. The sheet material, and sometimes paper as well, may be used by forming it into corrugations, or crumpling it in such manner that, when placed around the pipe, small quantities of air are caught in the corrugations and, being unable to escape, form a non-conductor around the pipe. If these coverings will prevent the cold from condensing the steam they will also prevent the heat from being radiated throughout the surrounding space.

Where pipes pass through the open air they are sometimes protected by building a wooden box around them which is filled with shavings and sawdust. The pipes may also be covered with some kind of felt. All of these substances serve similar purposes when properly employed.

There is a wide difference in the value of different substances for protection from radiation, their values varying nearly in the inverse ratio of their conducting power for heat, up to their ability to transmit as much heat as the surface of the pipe will radiate, after which they become detrimental, rather than useful, as covering. This point is reached nearly at the heat of baked clay or brick.

Air space alone is one of the poorest of non-conductors, though the best owe their efficiency to the numerous minute air cells in their structure. This is best seen in the value of different forms of carbon, from cork charcoal to anthracite dust, the former being three times as valuable as the latter for this purpose, though in chemical constitution they are practically identical.

Any suitable substance used to prevent the escape of steam heat should not be less than one inch thick.

The following table of the relative values of various substances for protection against radiation has been compiled from a variety of sources, principally from the experiments at the Massachusetts Institute of Technology, and those of C. E. Emery, M. E.

TABLE OF RELATIVE VALUES OF NON-CONDUCTING MATERIALS.

Substance.	Value.
Mineral wool	.68 to .83
Carbonate magnesia	.67 to .76
Paper	.50 to .74
Sawdust	.61 to .68
Asbestos, paper	.47
Asbestos, fibrous	.36
Air space, undivided	.14 to .22
Baked clay, brick	.07

A smooth or polished surface is of itself a good protection, polished tin or Russia iron having a ratio, for radiation, of from 53 to 100 for cast iron.

Hair or wool felt and most of the better non-conductors have the disadvantage of soon becoming charred from the heat of steam at high pressure, and sometimes of taking fire therefrom.

Mineral wool, a fibrous material made from blast-furnace slag, is the best non-combustible covering, but it is quite brittle and liable to fall to powder where much jarring occurs.

QUESTIONS.

1. What are pipes and tubing?
2. How are they measured?
3. What is a fitting?
4. Sketch and describe several fittings.
5. Describe a union.
6. What is a valve?
7. Sketch and describe a globe valve.
8. Sketch and describe a check valve.
9. Sketch and describe a gate valve.
10. Sketch and describe a reducing valve.
11. Sketch a steam trap and describe its operation.
12. What is a steam separator?
13. What is a grease extractor and what is its use?
14. How may the flow of steam through pipes be determined?
15. What effect has friction on the flow?
16. Give the rule for finding the flow of steam through a given opening.
17. What is packing and its use?
18. How may condensation of steam be prevented?

CHAPTER XVIII.

ROTARY ENGINES.

Heretofore, we have considered only the construction of the reciprocating engine. However, there is now being very largely used the rotary engine or turbine.

Strange as it may seem, the turbine was the original form of steam engine, one of this kind having been operated as far back as 120 B.C., when Hero of Alexandria described such an apparatus, utilizing heat energy. But this type of engine was neglected, as far as commercial purposes were concerned, until recently, when the turbine was again taken up and put to practical use. The essential principle of the turbine consists of a wheel containing vanes or plates against which a column of steam is projected, causing it to rotate. We have already seen, in the reciprocating engine, how advantage is taken of the expansive power of steam. In the steam turbine the process is quite similar except that there is a constant, instead of an intermittent, flow and the rotation being continuous and in one direction there is no variation in the amounts of power developed at any point. The steam continuously forced into the nozzle by a pressure at the point of inlet and during its passage through the turbine expands continuously, on account of its internal energy, and hence a particle of steam pushes those ahead of it at a faster rate, thus increasing the velocity of the flow. In the turbine the steam is caused

to impinge upon the vanes by means of nozzles, compelling the wheel to rotate as a direct result of the impulse and reaction of the impinging jet.

Impulse, as generally understood, is a force acting in a forward direction, and reaction is the equal and opposite force. For example, in the diagrams in Fig. 81, at *a*, a jet of water impinges on a flat plate and the force tending to push the plate away is entirely due to the impulse of the jet.

Should we arrange the surface in a curved manner,

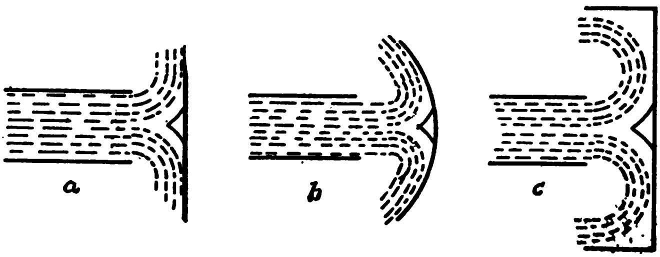


Fig. 81.

as shown at *b*, the water on striking the surface will be turned backwards and the force acting on plate *b* will be greater than that on *a*, depending on the amount of backward inclination which occurs.

Should we have a complete reversal of the original direction as at *c*, the force on the plate is practically twice as great as that at *a*, due to the combined effect of impulse and reaction.

The principal distinction between the types of turbines is the fact of the expansion being completed within the nozzle in one case, and after passing into the wheel in the other.

As the expansion of the steam in an impulse turbine is completed within the nozzle, no expansion takes place in the wheel passages.

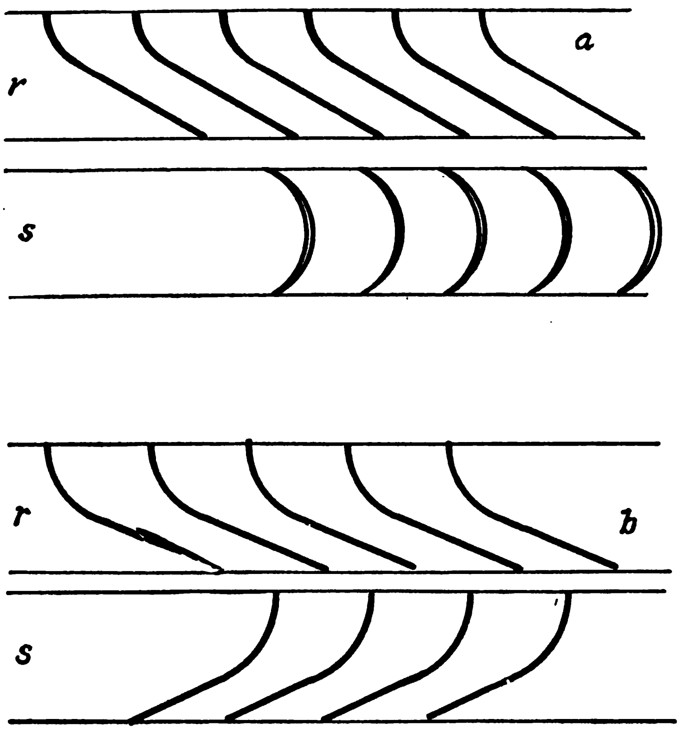


Fig. 82.

The pressure of steam between the vanes is the same as the pressure within the casing in which the wheel runs. The moving element is thus driven first by the pressure due to the impulse and then by the reaction

of the steam. In the reaction turbine the expansion in the nozzle is only partial, therefore it expands still more in the wheel when it leaves the vanes as the result of the energy acquired in the wheel itself.

In Fig. 82, at *a*, are illustrated the guide vanes and moving parts of an impulse turbine, while *b* illustrates similar diagrams of a reaction turbine. The moving and stationary parts are indicated by *r* and *s* respectively. These merely illustrate the principle and not the actual method of fastening in a turbine wheel. The two general classes, impulse and reaction, may be again subdivided into simple and compound.

In a simple turbine the steam from the nozzle is directed against the vanes of a single wheel. It is often necessary, however, to avoid such high speed of rotation as would be obtained with this design and also to do away with the reducing gears. This is accomplished by using several wheels alternating with the stationary guide, as shown in Fig. 83. With this arrangement only part of the energy from the steam is imparted to each wheel, and a much lower speed is the result. In addition, some compound turbines are divided into stages, that is, two or more wheels and guides are arranged in separate compartments. Each group is called a stage and the number of stages in any turbine will depend upon the subdivisions made. The advantages usually claimed for steam turbines are small floor space, close speed regulation, freedom from vibration, high economy under variable loads, small cost for maintenance and attendance.

One of the early representative turbines was that of

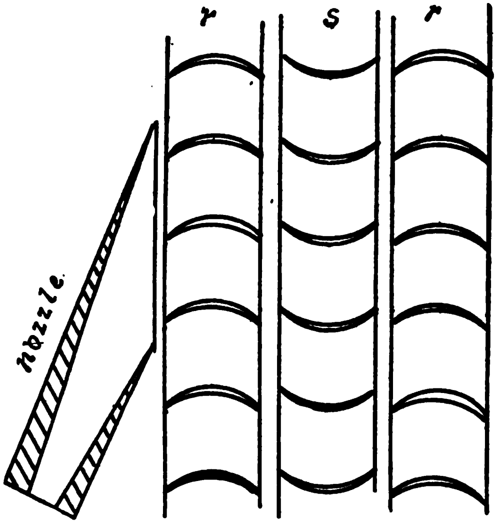


Fig. 83.

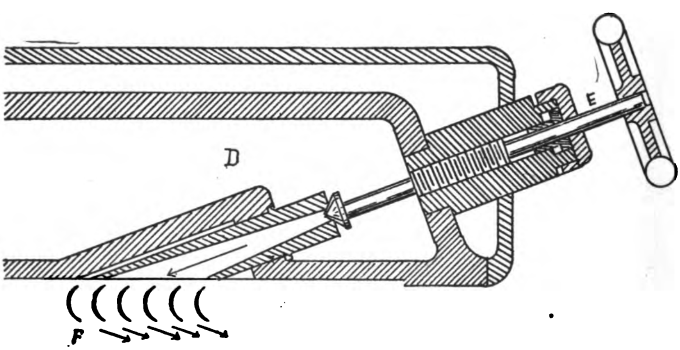


Fig. 84.

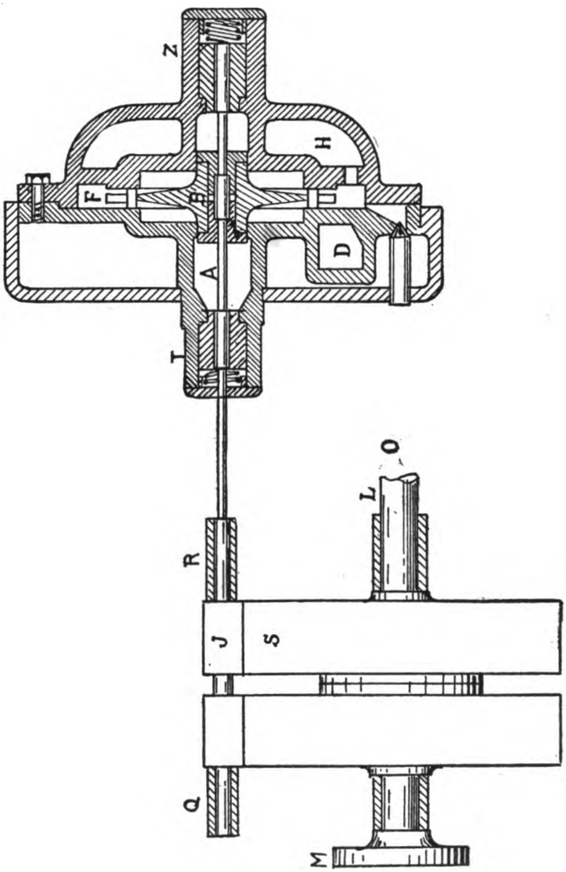


Fig. 85.

De Laval, originally designed in 1883 with the idea of operating a cream separator. It has since developed into engines used for greater powers. By use of the diverging nozzle, Fig. 84, he secured a complete adiabatic

expansion of the steam and a complete conversion of static into kinetic energy.

The general construction of the De Laval steam turbine will be clearly understood from the sectional plan and elevation, Fig. 85. The construction of the turbine presents no extraordinary departure from every-day engineering practice. However, the workmanship and material used, owing to the high speed employed, must be of the very highest quality. In the figure, B is the turbine wheel mounted upon the slender flexible shaft A, and in such position relative to the wheel case as to revolve entirely free, liberal space being allowed on each side, as shown. The wheel case and the wheel-case cover are so shaped as to form *safety bearings* around the hub of the wheel for the purpose of catching and checking its speed in case of an accident to the shaft.

The steam after passing through the governor valve, Fig. 86, enters the steam chamber D, Fig. 84, where it is distributed to the various nozzles. These, according to the size of the machine, number from 1 to 15. They are generally fitted with shutting off valves, E, Fig. 84, by which one or more nozzles can be cut out when the turbine is not loaded to its full capacity. This allows steam of boiler pressure to be almost always used, and adds to the economy on light loads.

After passing through the nozzle, the steam, as elsewhere explained, is now completely expanded, and in blowing through the buckets F, Fig. 84, its kinetic energy is transferred to the turbine wheel. After performing its work the steam passes into the chamber H, Fig. 85, and out to the exhaust opening.

The velocity of the turbine wheel and shaft, in most cases too great for direct practical utilization, is considerably reduced by means of a pair of spiral gears, usually made ten to one. These gears are mounted and

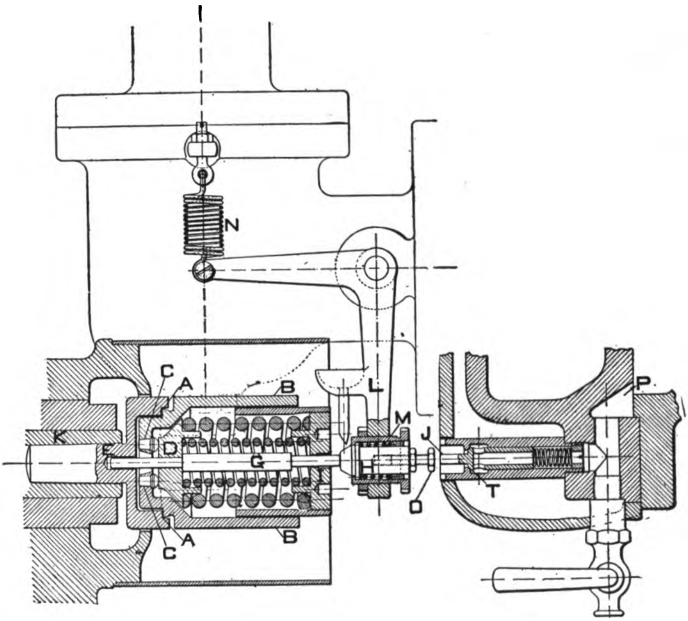


Fig. 86.

enclosed in a gear case. In Fig. 85 J is the pinion made solid with the flexible shaft; *S* is the spiral gear which, with couplings M, connects with the dynamo, or is extended for pulleys. At O is placed the governor, held with a taper-shank in the end of the shaft L, and by means of the bell-crank L, Fig. 86, operates the governor valve.

The governor is shown in detail in Fig. 86. The two weights B, B are pivoted on the knife edges A with hardened pins bearing on the spring seat D. The governor body E fits the end of the shaft K. It is reduced in diameter at its outer end and threaded for an adjusting nut.

When the normal speed is exceeded, the weights spread apart and, pressing on the seat D, push the governor pin G forward, cutting off part of the flow of steam.

The flexible shaft is supported on three bearings, Fig. 85. Q and R are the pinion bearings and Z is the main shaft bearing which carries the greater part of the weight of the wheel. This latter bearing is self-aligning and is held to its seat by the spring and cap shown. T is the flexible bearing which is entirely free to oscillate with the shaft, and its only purpose is to prevent escape of steam when running non-condensing or to prevent air from entering the wheel case when the turbine is running condensing. All the bearings of the flexible shaft, as well as the gear wheel, are lubricated from the central oil reservoir, mounted upon the gear case; all other bearings are self-oiling.

The gear wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90 degrees to each other. This, while insuring smooth running, at the same time checks any tendency of the wheel and shaft to move lengthwise. Owing to the high speed of the gears and their perfect alignment the stress on the teeth is extremely small.

The flexible shaft is mainly supported on each side

of the pinion by the main bearings, Q and R, the shaft being at the same time made very slender, which gives it a certain amount of flexibility and allows the turbine wheel, when the so-called critical speed is reached, to revolve around its true center of gravity. This critical speed, dependent upon the flexibility of the shaft, occurs well below the normal speed of the turbine and marks the disappearance of all vibrations.

The turbine wheel is by far the most important part, and is made of forged nickel steel. In the smaller sizes the turbine wheels have a hole through the center and are forced upon a tapered sleeve shrunk on to the shaft. The larger wheels are made solid, with the shaft in two pieces screwed to the flanges of the wheels. The buckets are drop forged and made with a bulb shank fitted in slots milled in the rim of the wheel. By this method the buckets can easily be taken out and new ones inserted, should occasion require, without damage to the wheel.

The vacuum valve is only necessary when running condensing, as in this case it has been found that the governor valve alone is unable to hold the speed of the turbine within the desirable narrow limit during sudden and great changes in the load. The function of the vacuum valve is as follows:

The governor pin G, Fig. 86, actuates the plunger H screwed into the bell-crank L, however, without moving the plunger relative to said crank. This is on account of the spring M being stiffer than the spring N, whose purpose it is to keep the governor valve open and the plunger H in contact with the governor pin. When the

large part of the load is suddenly thrown off, the governor opens, pushing the bell-crank in the direction of the vacuum valve T. This closes the governor valve, which is completely shut off when the bell-crank is pushed so far forward that the screw O barely touches the valve stem J. If this is not sufficient to check the speed, the plunger H is pushed forward in the now stationary bell-crank and opens the vacuum valve. This allows the air to rush into the space P, where the turbine wheel revolves, effectually checking its speed.

The Curtis steam turbine is interesting, due to the fact of being a vertical turbine, that is, one in which the wheel revolves horizontally, the central shaft being placed on end. Steam is admitted to the vanes or blades in a similar manner to the previous description, expanding to some extent, and passing through a set of blades, placed on a support, rotating on its center.

It then passes through a set of stationary blades, after which it enters another set of moving vanes, in which more of its energy is given up. In Fig. 87 is shown the diagrammatic arrangement of the blades and nozzles. Steam is admitted through the valves at *a*, controlled by the governor, and passes into the nozzle *b*. Partial expansion takes place here, and the velocity is increased. Then striking the moving blades *c* it passes through them to the stationary blades *d*, after leaving the last set of moving blades *c*, it exhausts into the atmosphere if running non-condensing. Should the turbine be operated condensing, the steam will pass into another set of nozzles *b′*, through another number of fixed and movable blades, and then exhaust into a condenser at *e*.

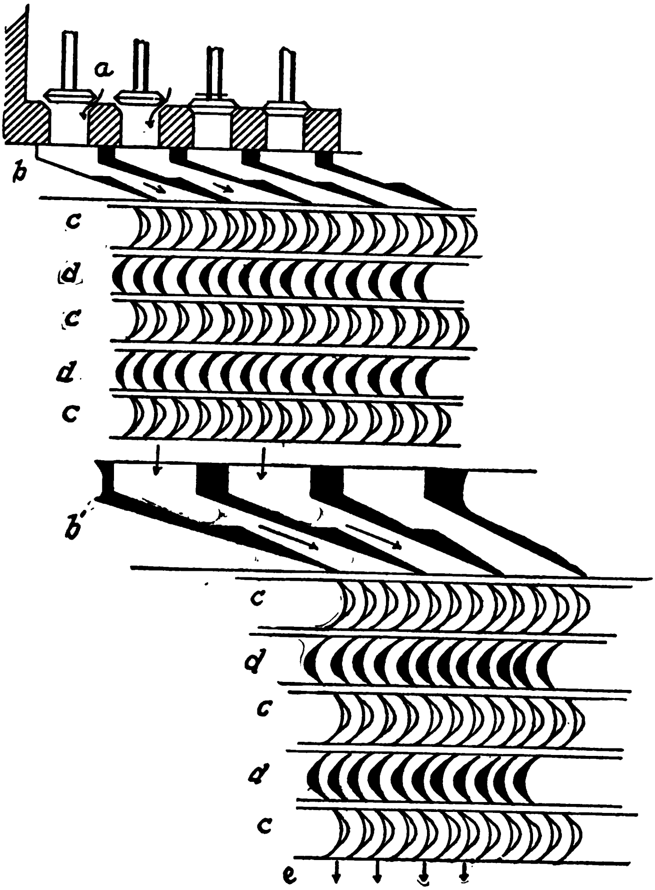


Fig. 87.

The sets of stationary blades serve to change the direction of the steam, in order that it shall always strike the moving vanes in the same direction. Each of these

two sets of nozzles, moving vanes and stationary ones, forms a pressure stage as it is called.

The turbines are made in from one to four pressure stages.

The Parsons turbine is possibly one of the best examples of the pressure type of turbines. In Fig. 88 is shown a section illustrating the principal parts of the machine. The main shaft A, resting in proper bearings, carries all of the revolving parts. At B, B′, and B″ are shown three sets of blades of different sizes. The revolving or rotating portion is called the rotor. The steam enters the turbine at boiler pressure through the valve H, and fills the chamber I, which extends around the rotor. From this chamber the steam expands through a set of stationary blades, so placed that the steam is made to strike the moving blades and cause them to rotate. The stationary and moving blades alternate in sets, forming a ring around the rotor. The velocity of the steam increases while passing through the stationary blades and decreases on account of the energy which it gives up while passing through the moving blades. These blades are set in a radial position similar to the De Laval, but instead of only one set being used, a very large number is employed. The length of the blades in any one set is the same. In the first series they are comparatively short and close together, but their length and distance increase in the next series. This is to accommodate the expansion of steam, the volume of which gradually increases as it passes onward. After the steam has passed through the first series of blades, it enters the chamber J, from which it enters

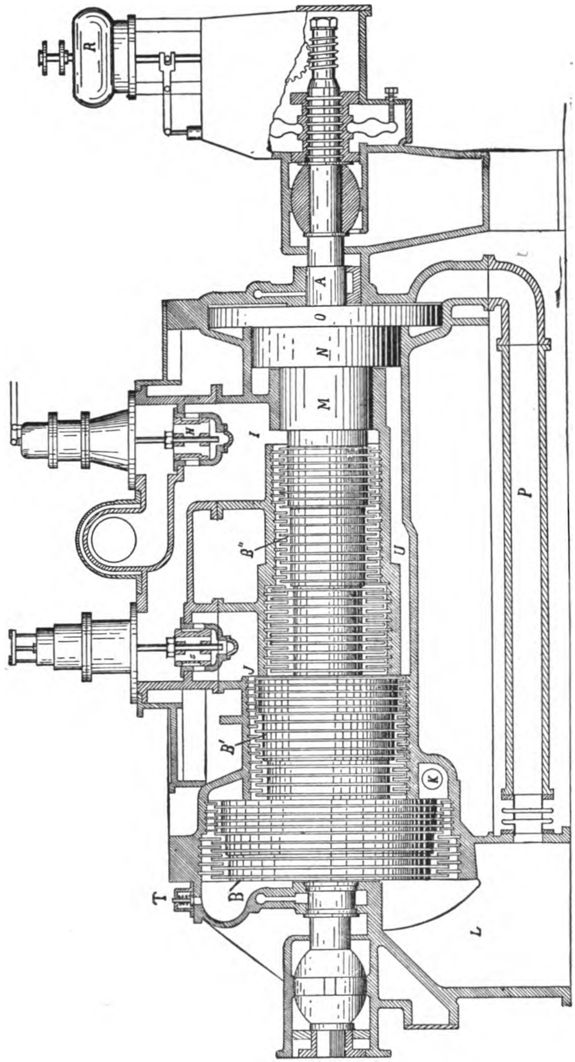


Fig. 88

the second series of blades B′. After passing through this series and out into the chamber K, it passes through the third series and exhausts into the chamber L, from whence it passes either to the atmosphere or to the condenser. The pressure on turbines of this character, due to the flow of steam always in one direction, will produce a tendency to force the central shaft in the direction the steam is flowing. The considerable end thrust thus produced is compensated by the balance pistons M, N, and O, these being of approximately the same diameter as the series of rotating vanes. Their surface is acted upon by the same amount of steam pressure, being connected by the passage U. They serve to equalize the tendency of the shaft to be pushed in one direction. Through the pipe P, connection is established with the chamber L, and access to the face of the piston O is thus provided for the exhaust steam in order to neutralize the pressure on both ends of the rotor.

In some of the modern engines, two turbines are employed rotating in the same direction but through which the steam passes in opposite directions so as to prevent the end thrust.

At R is placed the governor which regulates the speed by acting on the steam admission valve H. When the turbine is overloaded, the governor also causes the valve S to open and admit steam at boiler pressure to the second series of blades. A relief valve T allows the steam to escape to the atmosphere when the exhaust pressure becomes excessive. In steam engines it is convenient to express the economy by the pounds of

steam consumed for an indicated H.P. per hour. In the turbine, as indicator cards cannot be taken, the economy is expressed in pounds of steam consumed per brake H.P. per hour.

Turbine steam consumption is approximately equal to the best compound condensing steam engine, perhaps not quite equaling the best triple expansion of the ordinary type.

QUESTIONS.

1. What is a turbine engine?
2. Give some advantages of these engines.
3. How is the motion produced?
4. How do impulse and reaction differ?
5. How is advantage taken of this in a turbine?
6. Describe a De Laval turbine.
7. Describe the action of a Curtis turbine.
8. Describe a Parsons turbine.
9. What is a two-stage turbine?

CHAPTER XIX.

INTERNAL COMBUSTION ENGINES.

Attention has already been called to the fact of losses taking place in the ordinary plant largely due to radiation in the boilers, to the loss in transmission from the boiler through the pipes leading to the engine, and in the engine itself. All of these imply that considerable space is required for the apparatus employed in producing the power. In an internal combustion engine, fuel is introduced directly to the cylinder where its power is to be developed, and is consumed therein.

These engines are built in sizes ranging from 1 H.P. to 2000 H.P., and various fuels are used to provide the power. While they are generally known as explosion engines, this term is not quite correct, as the explosion is merely apparent; it is, in fact, rapid combustion. The fuel, having been introduced into the cylinder and placed under compression, is ignited; the combustion produces rapid expansion, so rapid that the effect is similar to that of an explosion. Fuels used for this purpose may be liquid or gaseous in their commercial form, but require to be changed into a gas on admission to the engine cylinder. They are principally gas, such as the ordinary illuminating gas, gasoline or naphtha, kerosene, denatured alcohol and blast-furnace gases. All of these contain a large amount of carbon, which, when mixed with a proper amount of oxygen, produce

rapid combustion. The presence of oxygen and its thorough mixture with the fuel gas is absolutely necessary to produce complete combustion. Such a combination produces intense heat. The theoretical heat value is never obtained in the cylinder, because there are always present quantities of certain other material in the fuels which are not readily consumed, and which absorb a considerable amount of the heat of combustion.

Water gas, used as a fuel, is a mixture of carbon monoxide and hydrogen. In producing it steam is brought in contact with incandescent carbon in the form of coal or coke; the steam is decomposed, the hydrogen being separated from the oxygen. The oxygen takes up carbon from the coal and forms carbon monoxide with a small percentage of carbon dioxide.

These gases chemically separate, but mechanically mixed, form what is called carbureted water gas.

Oil gas is made in a manner similar to the coal gas, by heating the oil to a very high temperature, and causing the heavy hydrocarbon it contains to break up into gaseous forms. Petroleum is largely employed for this purpose.

Isolated or self-contained plants, that is, those which manufacture their own fuel, generally use producer gas.

There are two types of producers, known as suction and pressure producers, based upon whether the movement of the gas through the producer during its formation is obtained by the suction of the engine in operation, or by means of a pressure apparatus pumping the gas through the producer. The process consists of passing a mixture of air and steam through a bed of burning

coal or similar fuel in a vessel called the *generator*. The combustion of this fuel takes place in the lower part of the vessel and generates carbon dioxide. The larger part of this is decomposed while passing through the bed of heated carbon, forming carbon monoxide. Steam entering the upper portion of the producer is decomposed, on account of the high temperature, into hydrogen and oxygen. The two operations absorb considerable heat, so that the combined results tend to effect a balance of temperature more or less controllable through variation of the amounts of steam supply. It is then allowed to pass on through the producer where it is cleaned, washed, and supplied to the engine.

The general appearance of a suction gas producer is given in Fig. 89, in which the evaporator for supplying the necessary moisture to the air is mounted directly above the producer shell. The apparatus consists of the producer *a*, with a cast-iron shell; the hand-operated blower *b*, for reviving the fire after a shut-down over night; the evaporator *c*; the hopper *d*; the water trap *e*; the water-seal box *f*; the scrubber *g*; and the gas tank or reservoir *h*. At each suction stroke of the engine air is drawn into the top of the evaporator *c*, through the elbow *i*, which is open to the atmosphere. The evaporator is filled with water from a branch pipe taken from the main supply pipe and kept at a constant level by an overflow pipe, not shown in the illustration, that carries any surplus supply to the ash-pit *j*. The water in the evaporator is heated to about 170° F., by radiation from the burning fuel and by the hot gases that leave the producer through the port *k*.

The air, passing over the surface of the hot water, absorbs a quantity of vapor, depending on the temperature of the water; so that the quantity of the water vapor admitted with the air through the pipe *l*, to the space below the grate, is greater when the fire is hot

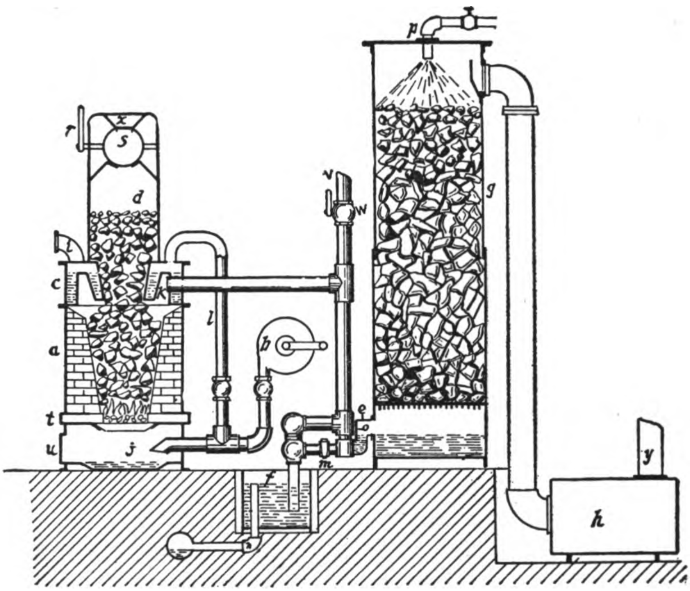


Fig. 89.

than when it is low. The fire is hottest, of course, when the engine is carrying a heavy load. Under a heavy load, not only does the increase in the amount of vapor enrich the quality of the gas generated, but the moistened air also has a correspondingly greater cooling effect on the grate and tends to keep the fire at a proper degree of intensity.

After entering the ash-pit below the grate, the mixture of air and steam is drawn upwards through the hot bed of fuel, where the steam is decomposed into hydrogen and oxygen, and the formation of carbon monoxide takes place. After transferring a portion of its heat to the water in the evaporator, the gas leaves the producer through the port *k*, passes through the water trap *e*, and enters the scrubber at the bottom. The water trap has two pipe connections to the water seal-box *f*, the lower pipe being provided with a valve *m*. While the plant is in operation, this valve is opened and the water that accumulates in the bottom of the scrubber flows through the lower connection to the seal-box *f*, and thence through an overflow pipe *n* to the sewer. When the plant is shut down, the valve *m* should be closed, thus causing the water in the trap *e* to rise well above the lower end of the partition wall *o*. This closes the gas connection between the producer and the engine. Any excess of water then flowing to the seal-box passes through the upper pipe attached to the trap *e*, and thence to the sewer.

While the gas is rising through the coarse coke in the scrubber *g*, it is met by a descending stream of cold water which is distributed evenly over the area of the scrubber by means of the sprinkler *p*, attached to the top cover-plate. In this manner, the gas, from which some of its impurities have been removed while passing through the trap *e*, is now cooled and washed sufficiently to be delivered to the gas tank *h*, in such condition that it contains no tarry or dusty substances to interfere with the successful running of the engine.

Fuel is supplied to the producer through the charging device mounted above the hopper *d*, which consists of the funnel *x*, and a smooth hollow ball *s*, that can be turned on its round seat by the hand lever *r*. The ball has an opening at the top, so that it may be filled with coal through the funnel, after which it is turned over by a quick movement of the hand lever, bringing the opening in the ball in communication with the coal space in the hopper *d*. As soon as the ball has thus been emptied of its contents, it is turned back and the operations of filling and emptying are repeated until the hopper is filled to the desired height. When not in use for filling the producer, the ball is held tightly on its seat with screws and hand-nuts. The quick turning of the ball leaves but a small fraction of a second, during which the hopper is opened to the atmosphere, and practically no air is admitted to the producer at that point.

The removal of clinkers that form in the fire space of the producer is facilitated by poke holes, with which the hopper is provided, that permit the fire to be stirred from above with suitable poking rods. The clinkers descend to the grate and are removed through the fire door *t*, on the side of the cast-iron shell of the producer, while the ashes accumulating in the pit below the grate are drawn out through the ash door *u*.

The hand-operated blower *b* serves to supply the blast necessary to start up the fire after the plant has been shut down for any length of time, as over night. During such a temporary shut-down, the process of gas making is practically stopped, except for the small amount of gas generated by the natural draft caused

by the flue pipe *v*, being kept open to the atmosphere by opening the flue valve *w*. While reviving the fire, the valve *w*, as well as a valve connected to the pipe *y* is kept open until the gas is of such quality as to burn with a bright blue flame, when the valves are closed and the engine is started in the usual manner. To secure prompt starting, it is found advisable to keep the valve in the vent pipe open to the atmosphere until a few explosions have taken place in the engine cylinder, and then close it.

Denatured alcohol, which is coming into use as a commercial fuel, is alcohol which has been rendered unfit for drinking by the addition of poisonous ingredients, such as wood alcohol and sometimes coloring matter. As compared with the better known fuel, gasoline, the combustion of alcohol is much more complete. The inflammability of the alcohol mixture is much lower, due, without doubt, to the presence of water in the alcohol which is vaporized with it and must be converted into steam at the expense of combustion. For the above reason the compression of an alcoholic mixture is higher than that permissible with a gasoline mixture without danger of spontaneous combustion.

Internal combustion engines are all similar in construction and principle but varying in detail according to the work which they are to perform, the condition under which they are to be used, and possibly with the fuel which they are to employ.

The following description of the construction and principles of operation of gasolene engines will serve, therefore, for all.

It will be noted, from Fig. 90, that there are two or three essential points in which these differ from steam engines. In the first place the absence of the cross head and connecting rod will be noted. With the exception of some of the larger gas engines, the internal combustion engines are single acting, that is, the pressure is exerted on one side of the piston only. This enables us to pivot the connecting rod directly to the piston *p*, by means of the piston pin *h*, thus shortening the engine to a considerable extent. The lower castings *c*, forming the crank case, act also as a support for the shaft bearings *r*. The piston, at the upper portion of its stroke, does not come as close to the head of the cylinder as in the case of the steam engine. This large clearance space is called the compression space. Its use will be seen later. The valves employ springs for closing, while they are opened by the cams *nn*, geared to the crank shaft. Some means for cooling the cylinder must be employed, on account of the very high temperatures developed by the combustion of the fuel. The spaces *ii* are a portion of the water jacket for cooling purposes. At *ee* may be inserted the ignition devices, and at *g* is the inlet valve, while *g'* is the exhaust. These engines are operated on what are called the two- or four-cycle principles. Other cycles have been introduced but are not yet generally employed. The four-part or Otto cycle, commonly called four-cycle engine, operates as follows: In Fig. 91 is shown the diagram of the engine in four positions. First, the piston is at the upper end of the cylinder, the crank shaft rotating in the direction shown by the arrow, thus

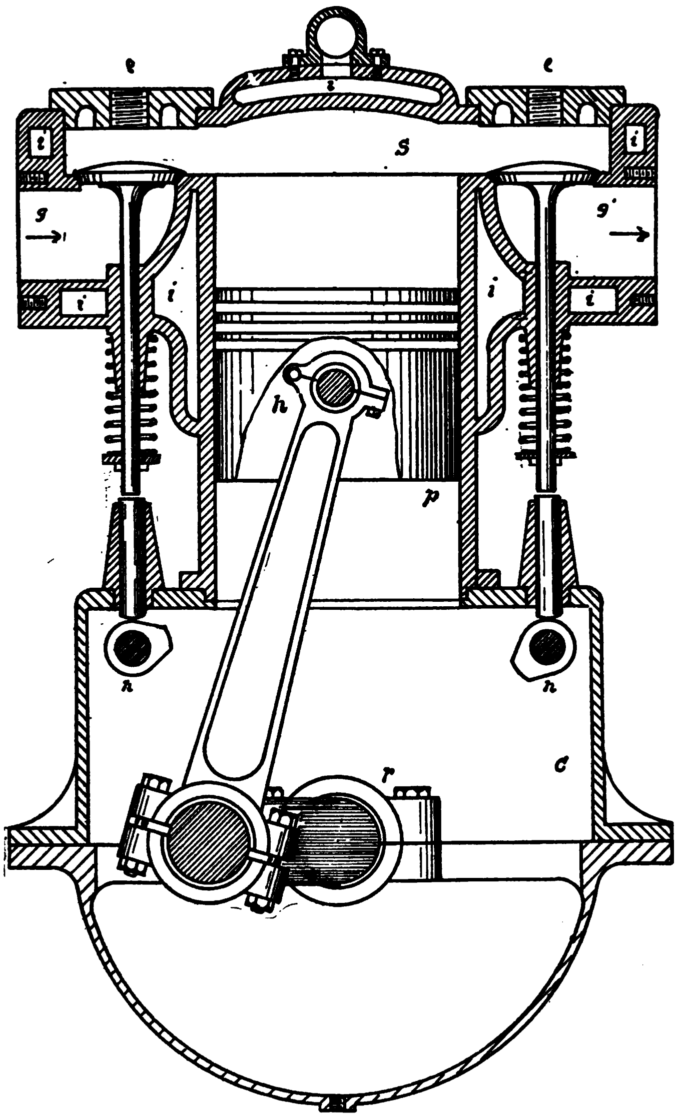


Fig. 90.

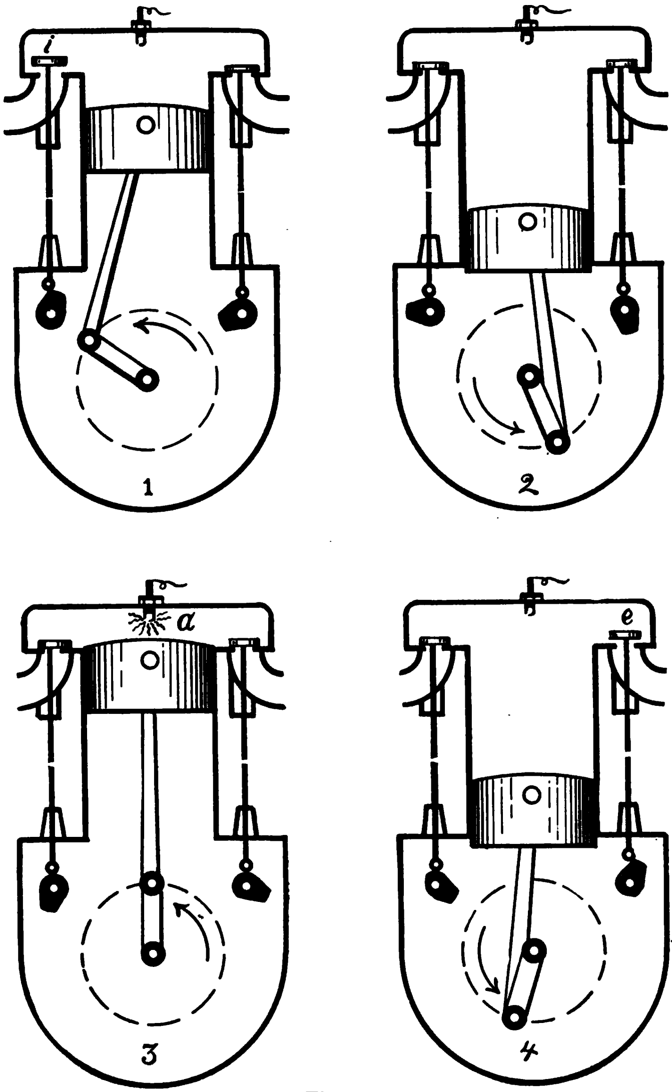


Fig. 91.

causing a partial vacuum to be produced in the cylinder. The inlet valve *i* is opened either automatically, due to the pressure of the atmosphere being greater than that of the partial vacuum in the cylinder, or mechanically by means of cams placed on a suitably connected shaft, as shown, and fuel in the form of a gas mixed with air enters the cylinder of the engine. At the end of this stroke the inlet valve has been closed by means of the spring on the valve stem. This constitutes the first part of the cycle. In the second part, the piston returns to its original position during the second stroke and both valves being closed the fuel cannot escape; as the piston rises the gas is compressed in the cylinder of the engine. As compression produces heat, a point can be reached where the gas will ignite due to this heat. The engine is designed to produce a pressure as near this point as possible with safety. This stroke, which is called the compression stroke, forms the second part of the cycle and also completes one revolution of the crank shaft.

As the crank passes the dead center and the piston is ready to move on the third stroke, the gases are ignited at *a*, and begin to burn and expand with great rapidity. The piston is forced outward with considerable power. The initial pressure generated in this case frequently rises as high as 350 pounds per square inch.

The piston now moves forward under the impulse of this pressure, the expansion taking place until the end of the stroke. The third part of the cycle is completed when the fourth and last part begins, by the opening of the exhaust valve *e*, allowing the gases to escape to the outer air. At the end of this fourth stroke, completing

the second entire revolution, the conditions arrive at the same point as they were at the beginning, and are then repeated. We have now completed an entire cycle of operation, by which is meant the going through of a certain number of definite actions in succession and then repeating them in exactly the same order.

Whereas our four-part cycle has required two complete revolutions of the crank shaft and four strokes of the piston, namely: the inlet or suction stroke, the compression stroke, the combustion or power stroke and the exhaust or scavenging stroke; a two-cycle engine has a power stroke at every revolution. In this case the gas, instead of entering and leaving the cylinder of the engine through valves operated as previously described, enters first the crank chamber *c* (Fig. 92) through the inlet *i*. On the upward stroke of the piston, a partial vacuum is formed in the crank chamber or case. The gases flow into and fill this space. When the piston has reached the upper part of its stroke and compressed a certain quantity of gas ready for ignition, as in the previous case, we will ignite this and produce the power stroke, forcing the piston down towards the bot-

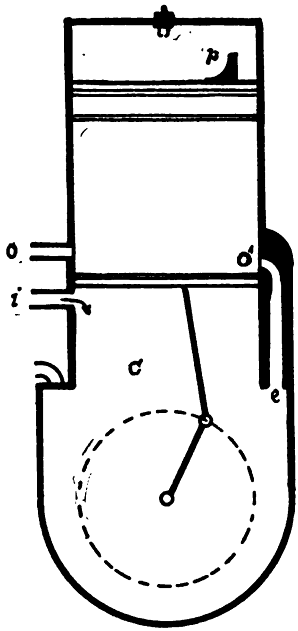


Fig. 92.

tom of the cylinder. The movement of the piston compresses the gas drawn into the crank case to a slight extent, perhaps some six or eight pounds per square inch. When the piston reaches nearly the end of the stroke, opening *o*, in the side wall of the cylinder, is uncovered. This opening communicates directly to the atmosphere and through it the burnt gases which have been producing the power make their escape. At approximately the same time the piston uncovers a similar opening *o′* in the opposite side of the cylinder. This opening connects, by the port *e*, with the crank case, in which is the fresh supply of gas at a low pressure. This gas, being released by the uncovering of the port, immediately rushes through into the cylinder of the engine. In order to prevent any tendency for it to pass across the cylinder and out through the port *o*, the plate *p*, called a baffle plate, is placed upon the piston head, which changes the direction of flow of the incoming gases, forcing them up toward the top of the cylinder, and thus allowing time for the greater portion of the exhaust gases to make their escape before the fresh charge can reach the port *o*. This completes the first stroke and first part of the cycle. On the return stroke both port openings are closed by the piston, compression takes place above the piston, a slight vacuum is produced below it, drawing in a fresh amount of gas to the crank case and, upon reaching the top of this stroke, ignition takes place, and the cycle of operation is continued. Therefore, in the two-cycle engine we have but one revolution and two strokes per cycle.

It will be borne in mind that in both of these engines

the power is intermittent, being exerted in the one case on every fourth stroke and in the other case on every alternate stroke. Evidently, then, the engine must tend to slow down between each of these points, and if some means were not devised for storing the energy of the power stroke, the action of the engine would be very irregular. Therefore, these engines, even more than the steam engine, require to be supplied with a fly-wheel, within which a part of the energy of the power stroke is stored and which returns some of this power, due to the momentum of the heavy fly-wheel, during the other strokes.

Mention has been made of the fact that the fuels must be supplied to these engines in the form of a gas which is mixed with a proper amount of air. This is done by means of a mixing valve or carburetor. The principle of the operation of the carburetor is as follows:

From a supply tank or reservoir of the liquid fuel (Fig. 93), a pipe *v* leads to the reservoir *c*, forming part of the carburetor. The liquid would drop from pipe *v* into the reservoir *c*, through the opening closed by the ball or needle valve *d*. In the reservoir *c* is placed a float *a*, either of cork or of metal, and as the liquid rises the float likewise rises, carrying with it the rod to which is fastened the valve *d*, so that when the float has reached a previously determined point, which point may be changed by varying the position of the float on the vertical rod, the valve is then closed and kept so by the pressure exerted on the float by the liquid.

The float is usually so adjusted that when the valve

d is closed, the level of the liquid will be about $\frac{1}{16}$ of an inch below the opening of the nozzle *z*. Surrounding the nozzle will be a pipe connecting at *f* with the cylinder of the engine. At the other end *g* it is open to the air. The pipe at the point where it surrounds the nozzle will probably be constricted, in order to increase the speed of the air traveling through it at that point. The pipe

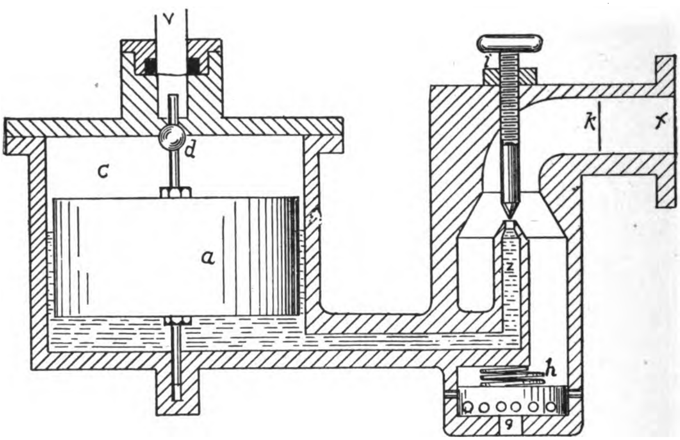


Fig. 93.

at *g* is partially closed by a light disc held in position by the spring *h*. This disc has several small holes in it, so that some air may pass through, even though the disc be upon its seat. At *i* the threaded stem of a needle valve regulates the amount of opening of the nozzle. If now the engine is turned and a partial vacuum produced in the cylinder, when the inlet valve opens connection is made to the carburetor at *f* and a rush of air into the cylinder takes place along the pipe from the point *g*. In going past the nozzle the velocity of the air

produces a partial vacuum which is immediately filled with the liquid from the reservoir *c*. The few drops of fuel mixing with the air are then carried up into the cylinder and on the way are thoroughly mixed, either naturally or by means of obstructions, such as strainers, put in its path to break up the liquid particles, also by the spraying action taking place at the nozzle. Upon reaching the cylinder it is in the form of a thoroughly mixed and combustible gas.

As the speed of the engine increases and a greater quantity of air is required to form a proper mixture, the increased suction, pulling on the perforated disc at *g*, overcomes the pressure of the spring *h*, lifts the disc and allows a greater quantity of air to enter through the holes on the side which connect with those leading to the atmosphere when the disc is lifted.

A suitable valve, or similar arrangement, in the main pipe at *k*, called the throttle, enables the amount of the mixture supplied to the engine to be readily controlled. Should the mixture be incorrect, in that either too much air or too much fuel is supplied, the result will be the same as regards the inability to supply the power demanded, because in either case complete combustion cannot take place.

In the case of oil engines employing kerosene or fuel oils, they are ignited under pressure in a highly heated compression chamber which has previously been supplied with the required amount of air, and which is carefully maintained at a temperature sufficiently high to vaporize and ignite the oil when injected into the compression space. The oil engine known as the American

Diesel operates on this principle. There are two distinct characteristics of the Diesel engine. First, — During the compression stroke, the cylinder contains air only, admitted during the suction stroke and then compressed to such a degree that the resulting temperature reaches a point amply sufficient to burn any liquid fuel injected into it.

Second, — There is not, properly speaking, an explosion, such as takes place in the ordinary internal-combustion engine; but the fuel is burned as it is introduced into the compressed air, and does not increase in temperature due to compression.

As previously noticed internal-combustion engines require to be cooled in some manner in order to obtain efficient operation. This is done either by radiation directly through metallic portions of the cylinder to the air, or by means of water. In a water-cooled engine, the cylinder and compression spaces, containing also the valves, are surrounded by a space called the water jacket, through which a constant flow of water is maintained, either mechanically or by means of a pump, or naturally by thermo-siphon principle. An important part of the cooling system is the radiator, composed preferably of copper tubes, provided with large flanges, in order to present as great a surface to the surrounding air as possible. The hot water being compelled to flow through this radiator gives up its heat to the copper pipes, which, in turn, transfer it to the atmosphere.

In the air-cooled type, which is not suited to stationary work, the cylinder casting is provided with a number of wide ribs, or else there are added to it a number of

ribs or pins of copper, firmly imbedded in the cylinder castings, for the purpose of radiating the heat. In this type, as well as occasionally in the water-cooled type, cooling is assisted by a blast of air forced against and around the cylinder and radiators by means of a large fan belted to the shaft of the engine.

The ignition of the fuel at the proper moment may be obtained in several ways: by heated gases and plates, as in the oil engines; by an open flame or heated tubes, as in many stationary engines; or by an electric spark, as is usually the case in engines employed to operate moving vehicles and in many stationary engines. The spark may occur in two ways: In the make- and break-type where the spark is produced on the opening of a closed electric circuit, or by the jump-spark method in which a high tension current leaps the space between two stationary points placed in the compression space. In either case the result is to ignite the gases. The current for the spark may be supplied from batteries, magnetos, or dynamos, operating on either low-tension or high-tension systems. The former is ordinarily employed in the make- and break-system. In this case, the primary current passing through a spark coil, in order to intensify it, ends in two points projecting into the compression space and in contact with each other. One point being movable, its amount, rapidity and time of movement is controlled by a cam placed on a rod outside of the cylinder, and in the control of the engine operator. In the case of the jump spark, a low-tension current produced by batteries, low-tension magneto or dynamo, is passed through the primary of an induction coil, pro-

ducing a high-tension current in the secondary of the spark coil. This high-tension current, or a high-tension current from a suitable magneto, may be employed. In either case it is led to two terminals in the form of a plug (Fig. 94). One side of the circuit being led to the terminal *a*, the other being grounded at some portion of the engine frame, forms, by means of the outer case of the plug itself, a terminal *b*; across the space between these two, the high-tension current leaps, producing the spark. The two terminals are insulated by a non-conductor *c*, formed of glass, mica or highly glazed porcelain. In engines of one cylinder the contact which closes the primary circuit may be closed by a simple cam and spring. In engines having two or more cylinders, an apparatus called the "timer" is employed, the principle of which is illustrated in Fig. 95. One side of the circuit leading from the batteries is grounded to the portion *a*, and sweeps around, making contact with the points *b* and *b′*, thus closing the circuit through the induction coils on these particular cylinders, and producing the spark.

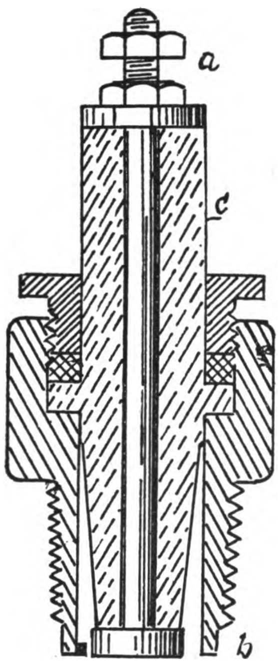


Fig. 94.

The time of spark production may be varied at will by the engine operator who controls the positions of the plate carrying the two or more contact points *b* and *b'*, closing the individual circuit. Should the spark be retarded, that is, take place after the piston has advanced some distance along the stroke, the gases would already have expanded to a considerable extent, less initial pressure would result and the engine would run more slowly. To speed up the engine, the spark is advanced, that is, brought to a point where it will occur at the instant the piston passes the dead center and begins to return on the previous stroke, thereby taking the fullest advantage of the compression of the gases.

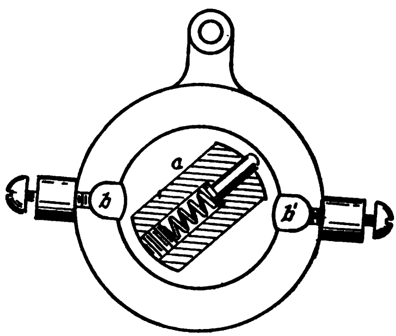


Fig. 95.

The amount and quality of the mixture supplied will determine the power delivered by the engine. Too great a quantity of the fuel will cause a deposit of carbon to coat the cylinder at the compression space and the plug. This may accumulate in the form of small projections which will become highly heated and ignite the gas before the desired point is reached, or may cause the engine to continue running after the igniting current has been shut off. It may also short circuit the plugs, thus providing an easier path for the current and a consequent missing of the spark.

On account of their higher pressure, the passage of the exhaust gases to the atmosphere produces an objectionable noise. This may be overcome by allowing them first to enter the chamber called the muffler in which they may gradually expand until a pressure more nearly that of the atmosphere is reached. They may then pass to the air in comparative silence.

Gas engine valves are made either with flat or angular spaces, fitting a similar seat, both seat and disc being ground together in order that there may be no possibility of leakage when the valve is closed. The seat is sometimes a portion of the cylinder casting, and sometimes a separate piece of metal which may be bodily removed with its valve from the engine in order to facilitate regrinding. This retaining casting is called a valve cage. Valves are brought to their seats by means of springs which hold them firmly in position and enable them to close quickly.

Stress has previously been laid upon the importance of having a correct mixture. A little thought will show that where the wear occurs, due to the valve stem passing through the cylinder casting, a leakage of air will also occur, sooner or later, which will interfere with the quality of the mixture. This has recently been overcome by the addition of a little attachment in the form of a collar placed on the valve stem and retained in position by a slight auxiliary spring. The opening through which the stem passes is beveled to fit a similar bevel on the attachment which may be so arranged as to close in on the stem and compensate for wear. As a result, this point is kept tight and an

improvement in regulation and efficiency of the engine is obtained.

As previously mentioned, some valves may be opened by the atmospheric pressure overcoming the lower pressure which is produced by the partial vacuum in the engine cylinder. Others mechanically open and close by cams placed on a shaft, or sometimes a separate shaft is provided for the inlet and exhaust valves. This shaft is geared to the crank shaft in the ratio of 2 to 1. It will also be observed in the description of the two-cycle engine that there are no valves in an engine of this type. In consequence of which it is much simpler, and does not require many of the adjustments of the four-cycle engine. In setting the valve cams, excellent results may be obtained by adjusting them so that the inlet valve begins to open when the crank or, as it is sometimes called, the *throw* of the crank shaft has traveled about 10° on the suction stroke.

The first five or six degrees of movement of the crank being almost at right angles to the line of action of the piston, it will produce no appreciable movement of the piston. By opening the valve, therefore, a short distance after center, a slight vacuum will be formed, and the supply of fuel will start to enter the cylinder with greater speed, which is a decided advantage. The exhaust valve may open fifteen or twenty degrees before the end of the power stroke and close at the center or five degrees after the end of the exhaust stroke. This will facilitate the emptying of the cylinder of almost the entire amount of burnt gases. These engines are made with varying numbers of cylinders, both to gain power

and to prevent vibration and strain upon the crank shaft. In Fig. 96 are several diagrams illustrating this point; those on the left may be called theoretical work diagrams and are divided into four vertical columns, representing the four strokes of the cycle. Horizontally each diagram consists of two columns, the shaded areas

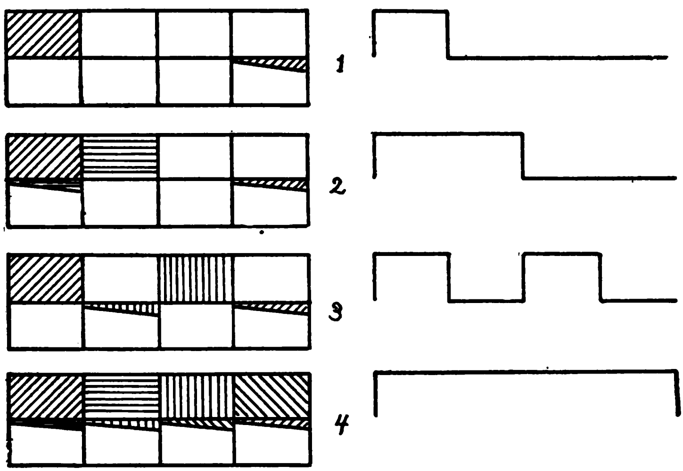


Fig. 96.

of the upper representing work done on the piston in propelling it forward and doing external work. The shaded part of the lower column is work done during compression and might be called negative work.

If the fuel is ignited with the engine at rest, the force of expansion will produce considerable strain on the shaft, while if the shaft is moving at a sufficiently high speed the shock will not be of an appreciable amount.

The shock or impulse diagrams on the right illustrate

this when ignition takes place during one or more strokes, as shown on the left.

No. 1 is for a single-cylinder engine, ignition taking place on the first stroke during which maximum speed is produced. During the next two strokes nothing is being produced, and during the last portion the engine is slowing down and a small amount of work is being done.

Then comes the force and shock of the next ignition, striking the piston and crank shaft, which are almost at rest, a hammer blow, which produces a strain of great amount on the shaft.

The diagram to the right (Fig. 96) would serve to indicate what we might call the shock or impulse diagram in this case. If two cylinders are employed, they may be placed side by side as in the twin engine *a* (Fig. 97), or opposite each other as in the opposed engine *b*.

In the first case, when the power stroke of one cylinder occurs, momentum is imparted to the fly-wheel, as will be seen by reference to diagram 2 (Fig. 96); when that stroke is completed and the engine is still in rapid motion, the second ignition occurs, delivering its power not with such a sudden shock, but adding simply to the impetus already acquired by the heavy moving parts. This advantage, to some extent, lasts during the next two strokes, where conditions somewhat similar to that of the single-cylinder engine occur, as are shown by the diagrams, but not to such an extent as in the first case, because there is not quite so much opportunity to slow down as where only one cylinder is employed.

With such an engine, if the course of the cycle be

carefully followed out, it will be seen that it is impossible to separate the moments of ignition by a stroke during which no ignition occurs, see *a* (Fig. 97).

In the two-cylinder opposed engine, as illustrated at *b* (Fig. 97), this may be done, and when ignition occurs

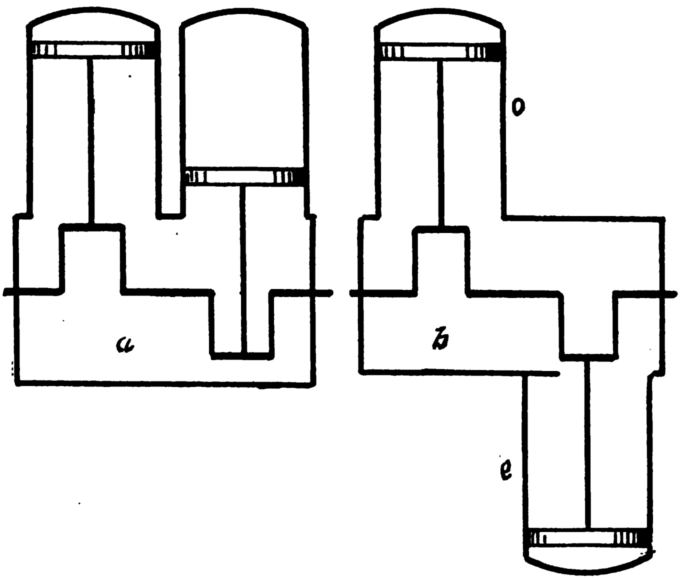


Fig. 97.

on the first or power stroke of cylinder *o*, the piston in cylinder *e* is on the suction stroke. On the second stroke of cylinder *o*, when it is exhausting, cylinder *e* is compressing. On the third stroke, cylinder *o* is drawing in the gas, cylinder *e* is on its power stroke, and on the last stroke cylinder *o* is compressing and cylinder *e* is exhausting. Therefore, as will be seen from the

impulse diagram (No. 3, Fig. 96) on the right, the power strokes occur alternately, or one during each revolution. In the meantime the engine has not had an opportunity to slow down to any appreciable extent. In consequence of which, the shocks are less wearing on the machine, and the vibration is far less than in the previous cases.

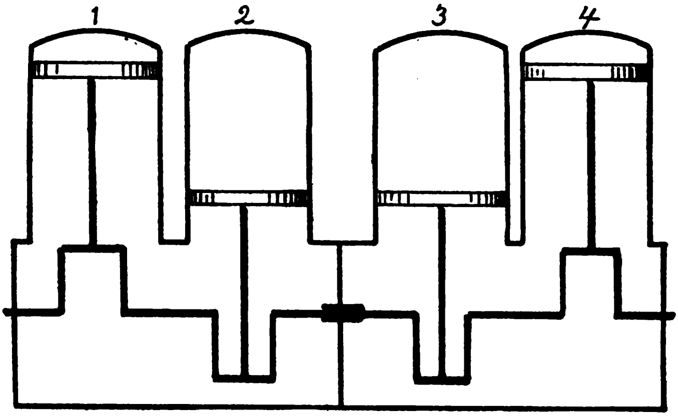


Fig. 98.

If, now, the engine be equipped with four cylinders (Fig. 98), we will have an engine similar in results to two opposed engines and on each stroke we will have a power impulse and compression; therefore, the impulse diagram will read as shown in (No. 4, Fig. 96), or practically a continuous turning movement is the result. The firing order of the cylinders in such an engine, reading from the left, might be arranged in the following order: Cylinders 1, 2, 4, and 3.

Engines are sometimes constructed with three cylinders, enabling the cranks to be placed at an angle of

120° to each other, with the idea of relieving the strain on the crank shaft. This is an excellent method for obtaining the desired results, but probably not as satisfactory as where four cylinders are employed.

In order to determine to some extent the horse power developed by a four-cycle gasoline engine the following formula may be employed:

$$\frac{0.7854 \times d^2 \times P \times e \times L \times N \times n}{2 \times 12 \times 33{,}000} = \text{H.P.}$$

n = the number of cylinders.

N = the revolutions per minute.

L = the stroke in inches.

P = the M.E.P. during the power stroke.

e = the efficiency factor.

The values of P and e, are not always readily determined with the means ordinarily at hand but may in a good engine be assumed to be respectively 70 pounds for P, and 0.75 for e.

We have, therefore, practically the same formula as that used in calculating the horse power of a steam engine.

This formula applies when the engine is running at its best speed for developing power; that is, about 800 revolutions for a motor of six-inch stroke, or 1200 revolutions for one of four-inch stroke.

However, owing to the many different and varying conditions developed in gas-engine operation no thoroughly satisfactory rule meeting all conditions has yet been developed. The Association of Automobile Manu-

facturers has adopted the following formula based on a piston speed of 1000 feet per minute.

$$\text{H.P.} = \frac{d^2 \times \text{No. cylinders}}{2\frac{1}{2}}.$$

Several diagrams illustrating methods of wiring for jump-spark ignition purposes are shown in Fig. 99. The simplest form is that used with a single-cylinder engine employing a battery as the source of current supply, and an induction coil to produce the high-tension current. This method is shown in Diagram No. 1. When the switch is closed, current from the battery will flow through the primary circuit *P*, through the coil *C* to the ground connection *G*, thence along the engine frame as indicated by the dotted lines to the timer shaft *O*, whenever the circuit is completed by the roller *R* touching the contact block *B*.

The induced current flows through the secondary circuit *S*, through the plug, and completes its circuit through the ground and a part of the primary circuit, as indicated on the diagram.

A diagram for a four-cylinder engine with four coils is shown by No. 2. The timer has four contact-blocks, Nos. 1, 2, 3, 4, each being connected to a coil, each coil being in turn connected to a spark plug in one of the cylinders. The timer is so connected that ignition will be produced in the cylinders in proper order as previously explained.

In such cases two sets of batteries are usually carried, and either one may be used by means of the switch shown.

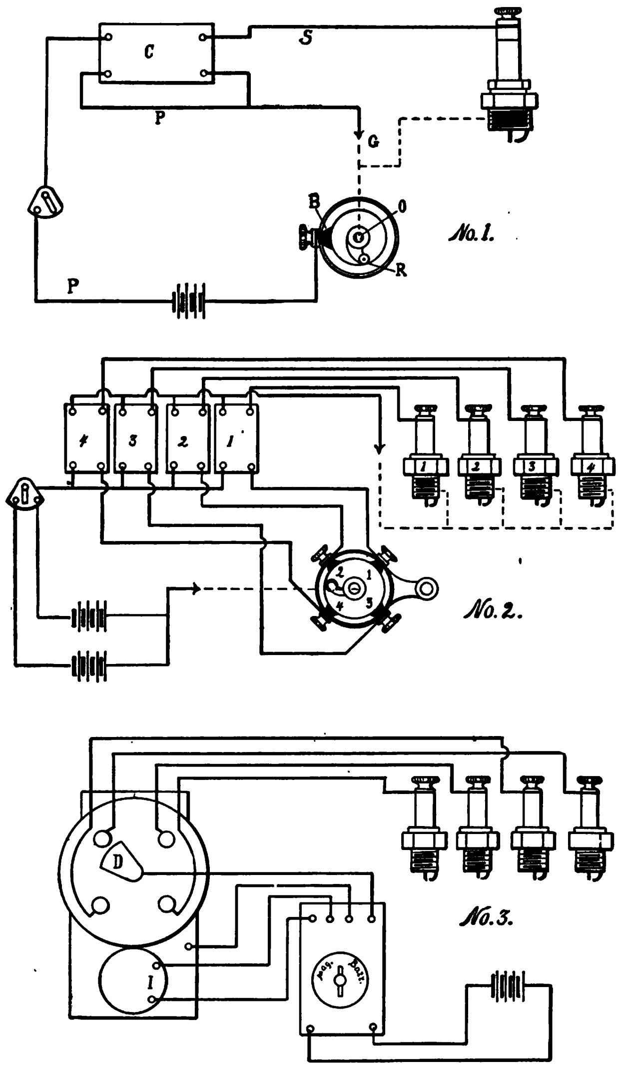


Fig. 99.

Where a magneto is used to produce the spark an auxiliary battery is frequently employed to facilitate starting the engine. Diagram No. 3 shows a method of wiring for this purpose.

With the switch on the battery side the primary current energizes the coil and passes through the interrupter of the magneto, to which it is connected at *I*. The distributor of the magneto *D* serves to deliver the secondary current to the proper plug. When the engine is running the switch is thrown to the magneto side and the battery is cut out.

QUESTIONS.

1. What is the principle of operation of an internal-combustion engine?
2. Describe the four-part cycle.
3. Describe the two-part cycle.
4. Wherein does this type of engine differ from a steam engine?
5. What is a carburetter? Describe it.
6. What is the cooling system?
7. Why are multi-cylinder engines preferable?
8. How are the valves operated?
9. What is a gas producer?
10. Describe its operation.

CHAPTER XX.

LUBRICATION.

When a piece of material is caused to slide over another, a certain amount of work is required to overcome the friction between the pieces. If these are moved with considerable speed heat will be produced. Should one of them be practically encircled by the other, as is the case of a shaft rotating in its bearings, the heat may cause sufficient expansion of the inner portion to make them bind closely together, thus requiring more work to move them, or perhaps requiring so much power to move them that it is entirely beyond the ability of the machine to do so, and it stops.

The normal friction, that is, friction due to ordinary causes, will be increased, depending on the diameter of the revolving shaft, on the weight placed upon it and upon the speed at which it revolves. The smoother the surfaces, the less friction there will be. Also, there will be more friction if both parts are of the same material. This is probably due to the fact that two pieces of material of the same kind and of the same quality will have molecules of the same size and of the same general form, so that when one piece moves over the other the projections on one piece drop readily into the depression in the other, somewhat after the manner in which the teeth of a gear wheel lock together. When dissimilar metals are employed for the shaft and bearings,

or for the stationary and movable parts of a piece of machinery, the particles composing them being of different size, those of one piece cannot drop so deeply into the depression on the other, and consequently less friction is produced.

In an engine, like all other pieces of machinery, we have many places where friction occurs, due to the moving of one surface on the other. We have parts of varying diameter, such as a crank shaft, or crank pin. We have the pressure exerted on these parts, too; for example, the pressure on the piston, the weight of the fly-wheel, the pull of the belt, the pressure on the guides and several other parts. In addition to the above we have, particularly in the cylinder, moving parts somewhat difficult to reach with the oil and exposed to a considerable degree of heat from the steam. On these places where friction occurs, materials of different quality are employed to reduce the friction for the reason previously given.

In the case of the connecting rod and crank pin, the end of the rod is fitted with bronze or gun metal bearings. This material is an alloy, varying in composition with regard to the service for which it is to be employed. A good grade is composed of about 90 parts of copper to 10 parts of tin. The hardness may be increased by increasing the proportions to 14 parts of tin to 86 parts of copper. In other bearings the bearing proper is recessed, and this recess is filled with some metal which has especially good anti-friction qualities, such, for example, as babbitt. This is a soft, white-colored alloy of copper, tin and antimony, in the proportion of 4

parts of copper, 24 parts of tin, and 8 parts of antimony. This is made into an alloy first, and then remelted with twice its weight of tin. When used it is melted and poured into the bearing with the shaft in place. It makes a smooth highly polished surface in which the friction is reduced to a remarkable extent. The mechanical reduction of friction is further obtained by making bearings partly of babbitt or bronze, containing grooves or recesses filled with graphite, or black lead. This, in its commercial form, is a shiny black, smooth, greasy feeling material, which is in itself an excellent lubricant.

Various constructions of modern machinery provide for bearings composed of balls or rollers formed of hard steel which support the shaft and, rolling around with it, also revolve upon their own centers, thus eliminating to a very great extent all sliding motion as in a plain bearing, and producing a rolling motion only. These methods of reducing friction, however, are not altogether satisfactory when taken alone. Recourse must be had to additional lubrication in the form of oils or grease which should be carefully selected with regard to the work to be performed.

A theoretically perfect lubricant is one which will penetrate to all portions of the bearing, form a thin film between the moving parts and remain there, entirely separating them, so that the moving parts of a properly lubricated bearing should never actually touch each other. Under these conditions the ideal bearing is that of a shaft rolling upon a large number of small spherical bodies represented by the drops or molecules compos-

ing the lubricant. Such lubricants in the form of liquids and semi-solid materials are called oil and grease. They vary in density according to the work to be performed.

A thin oil will not serve for a heavily weighted, slowly moving bearing, as it would be pressed out without doing any service, while a hard grease would not serve for a light and rapidly moving bearing, on account of not being sufficiently fluid to flow properly where desired. For many purposes, animal or mineral oils are used, but the animal oils are exposed to the objection that when decomposed they are liable to liberate acids or other substances which are injurious. In the case of engine cylinders, where, on account of the intense heat, the oil is likely to be evaporated or decomposed quickly, mineral oils are used.

Briefly stated, mineral oil is that which is drawn from the earth, being the product of natural causes during many ages of the earth's existence. It is supposed that at some period, long ago, vast quantities of animal and vegetable matter were caught during some convulsion of the earth and held between masses of material which afterwards solidified in the form of rock. Heat and pressure, due to the contraction of the earth, gradually squeezed out all the oil which collected in pockets in certain portions of the earth where oil is found. This same cause also distilled from the oils and materials which produced them certain lighter products or gas.

Occasionally these gases are found in spaces in the earth's surface connecting with the spaces in which the oil is found. If in drilling in an oil region, a body of oil

is struck which is connected by natural passage ways with a body of gas, on removing the drill and releasing the pressure, the gas forces the oil ahead of it out of the well pipe. This is called a "gusher." If there is no gas present or its pressure has been reduced then the oil must be pumped out of the well. Oil in this form is called *crude oil*. It has a specific gravity varying from 0.77 to 0.98. All crude oils have a fluorescence, varying from dark green to blue, and a very noticeable odor. The process of distillation is now undertaken, consisting essentially of heating the crude oil. At varying temperatures the liquid is liberated in the form of gas which is afterwards condensed. The gases liberated at the varying temperatures and the resulting oils are of various grades and are called distillates. The lubricating oils are nearly the last to be distilled, on account of the high temperature required to bring them to the boiling point.

After distilling they are refined by the use of various chemicals and then clarified by running into settling tanks, where they are allowed to remain until thoroughly cleaned.

In order to produce the commercial oil, various qualities of distillates are blended to give satisfactory results in operation.

Recently a method has been devised to obtain a very finely divided graphite called "deflocculated graphite." This is mixed with cylinder oil, and remains in suspension, thoroughly combining with the oil and greatly adding to its lubricating quality. This has not previously been possible as the graphite in the former commercial

forms refused to mix well with the oil and tended to obstruct the clear flow of the oil ways.

When grease is applied to bearings a receptacle called a grease cup is employed. These may be divided into two general classes. One is a plain metallic cup with a cover in which grease is packed and the heating of the bearing due to friction is depended on to gradually melt down the grease and cause it to flow on the bearing. In the other, the pressure grease cup, of which an example is shown in Fig. 100, a piston *a* is pressed down upon the grease by the spring *s*, forcing the grease continually to the bearing.

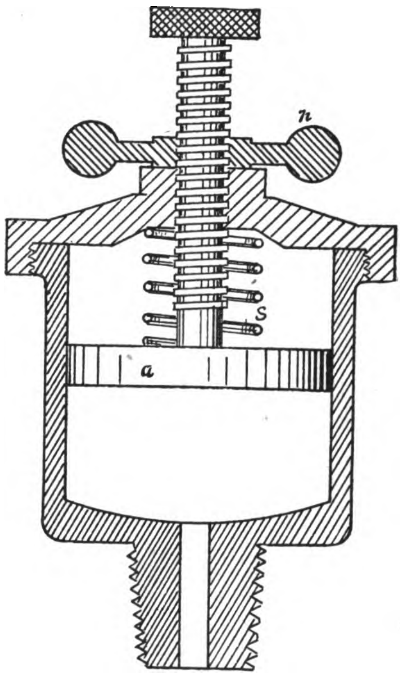


Fig. 100.

The wing nut *n* is used as a check on the spring. It is unscrewed a sufficient amount to allow the spring to move forward during the day's run and then it must of necessity stop until the wing nut is further unscrewed. The object is to prevent the grease from being forced into the bearing during periods when the engine is at rest, during

which time the extra lubrication would, of course, be valueless.

Very many types of oil cups are employed to meet the many conditions required in service. There may be a metal body or a body composed of a glass tube reinforced by metal, thus enabling the amount of oil in the cup to be readily determined. As these are generally arranged to supply oil, drop by drop, to the bearings, a valve arrangement is provided by which this may be regulated, also a glass tube below the cup, called the "sight feed," through which the nozzle, from which the oil drips, may be seen.

For the purpose of lubricating cylinders of gas engines or similar places where pressure is present, a pressure cup is employed, of which a cross section is shown in Fig. 101.

The glass body *g* forms a reservoir for the oil which may drip down into the connecting pipe through the nozzle *e* forming the end of tube *a*. The tube *b* also connects with the connecting pipe, its opening being closed by the ball check *c*. When compression in the engine cylinder occurs a portion of the gas escapes into the reservoir of the oil cup through the tube *b* and the check valve, forming a pressure on the surface of the oil. Oil cannot pass the nozzle as the check *c′* is held against its seat by the compression pressure. When, on the following stroke, the pressure in the cylinder of the engine, the nozzle *e* and its surrounding chamber, is reduced, the check *c′* drops, opening the nozzle passages; the captured gas retained in *g* by the check *c* is exerting pressure upon the surface of the oil

and forces a drop of oil through the tube *a* to the nozzle, from whence it is drawn into the cylinder by suction and gravity.

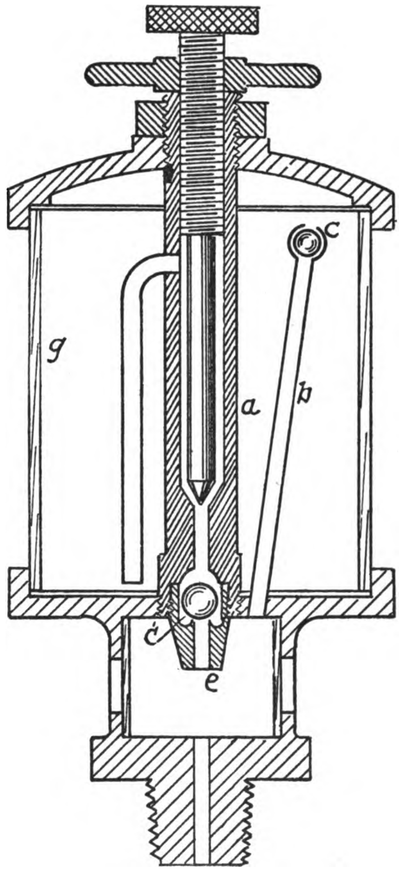


Fig. 101.

To lubricate a steam-engine cylinder is not easy, for one cannot well make an opening through which to insert an ordinary oil can when the pressure is in the cylinder; as the piston is constantly moving forward and backward, it requires lubrication to overcome the friction due to the weight of the piston resting on the bottom of the cylinder. For this purpose a lubricator is employed, the principle of which is illustrated in Fig. 102. The main steam pipe *a* has two openings in it, into which are connected the small pipes at *b* and *c*. These small pipes and the lubricator form a by-pass and afford, with the main pipe, two ways for the steam to pass from the point *d*

to *e*. Of course the major portion of the steam will pass through the main pipe *a*, but with the lubricator valves open a small portion of it will pass in that direction.

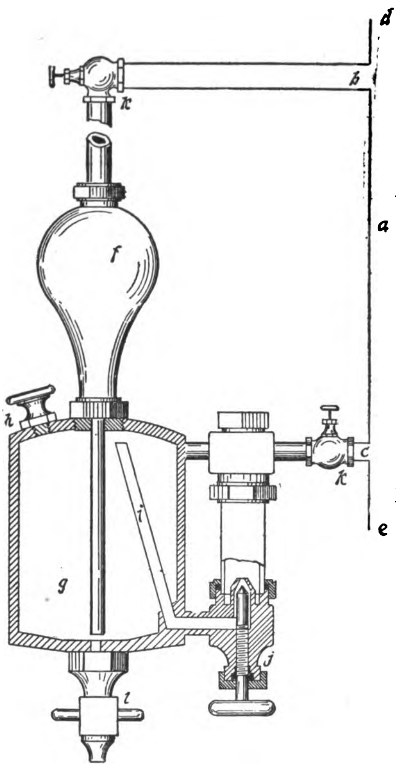


Fig. 102.

On entering the pipe *b* and proceeding to the large chamber *f*, the steam is condensed by coming in contact with the walls of this chamber, which are kept cool by the surrounding atmosphere. The condensed steam or water then drops to the bottom of the pipe forming a layer of water in the bottom of the cylinder *g*. This cylinder has previously been filled with oil through the opening *h*, which is now closed. As the water under pressure from the steam, in the pipe *b*, collects at the bottom of the cylinder, the oil floating on top of it tries to find some outlet. This is provided through the pipe *i*, ending near the top of the cylinder. Therefore, the gradual accumulation of water drives the oil, little by

little, through the pipe *i*, until, in the course of time, the cylinder has been entirely emptied of the oil. The pipe *i* ends in a nozzle, the opening of which may be regulated by the valve *j*. This nozzle is placed in a glass tube for convenience in noting the regulation of the feed, and the glass tube continuing in the form of a pipe joins the main line *a* at *c*. By means of the valve *j*, the amount of oil passing into the line is regulated for so many drops per minute, depending on the requirements. On reaching the pipe *a*, the drops of oil are taken up by the main body of steam and with it enter the steam chest and cylinder, where they are thoroughly distributed over the valve and cylinder walls.

When the oil in the cylinder *g* has become thoroughly exhausted it is renewed by first closing the valves *k*, *k′*, opening the valve *l*, and the plug *h*; the water now drains out. Then, on closing *l*, the cylinder may be refilled through the opening *h*, closing *h* and opening *k*, *k′* again; it is once more ready for operation.

Instead of using individual oil cups on each of a number of bearings on an engine, and sometimes also in the case of cylinder lubrication, a force feed oiling system is employed. This consists essentially of a supply tank from which oil is pumped, either directly by a small pumping attachment or by forcing air under pressure into the reservoir; in either case the oil is forced out into small pipes, each leading to and connecting with one bearing.

In this way a constant feed of oil is maintained to each point requiring it, and only one reservoir requires to be supplied with oil. After oil has been used upon

bearings it may be reclaimed, that is, collected in some suitable vessel, and when sufficient quantities are collected it may be cleaned and used again for bearings not requiring the highest grade of lubrication. It should not, however, be used over again in the cylinders of the engine. On high-speed machinery, such, for instance, as dynamos and motors, so-called self-oiling bearings are often used. In this case a reservoir of oil is placed a little below the shaft. Hanging loosely upon the shaft is a ring sufficiently large in diameter to reach to the bottom of the oil reservoir. As the shaft rotates this ring moves around in the same direction, carrying with it from the reservoir and depositing on the shaft sufficient quantities of oil to thoroughly lubricate it. When this oil runs off the shaft, it drops back into the reservoir to be used again.

QUESTIONS.

1. How is friction produced?
2. What is the result of friction?
3. How may it be reduced?
4. What is anti-friction metal?
5. Describe roller bearings.
6. What is a lubricant?
7. Under what conditions are oils or grease used?
8. Describe a grease cup.
9. Describe a compression, or force feed, oil cup.
10. Describe a cylinder lubricator for steam engines.

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